INTEGRATION OF FORAGE IN FARMING SYSTEMS

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ABSTRACT

Forage is often produced and used in an integrated farming system along with other crops and animals. The system is very complex including soil, crop, machinery, and animal components that interact with each other and the environment to enable the production of feed and animal products. Research has quantified and modeled many of the individual components and interactions. Comprehensive computer models that integrate the many processes provide useful research tools for evaluating the performance and economics of alternative technologies and management strategies in forage production. Opportunities for further development of research models include 1) integration of forages in cropping system models that evaluate production benefits along with externality costs to society, 2) integration of more crop options along with forages in animal production system models, and 3) integration of grazing and conserved forage systems in a more comprehensive animal production model. Research models can provide useful teaching aids when an extensive yet intuitive user interface is included. Although models are often promoted for use in farm management, most have not become useful management aids. Model complexity and lack of training often prevent users from relying on model results for decision making. More sophisticated user interfaces are needed to assist in setting model parameters and verifying and interpreting model results to encourage wider use of farming system models as management aids.

KEYWORDS

Forage, Cropping systems, Farming systems, Integration, Interaction, Models

INTRODUCTION

Forage crops are produced and used in virtually every country of the world. Most forage is grown on land classified as permanent pasture or rangeland, but a substantial portion is planted on arable land where it is rotated with other crops in a cropping system. Cropping systems are more complex than permanent grassland in that more processes must be considered with many interactions among these processes. By definition, cropping systems include more than one crop, and each crop must be established, maintained, and harvested with consideration of the other crops and processes on the farm. Often forages are produced in farming systems that include animals. The major animal consumers are beef and dairy cattle, sheep, and horses. Animals utilize forages through a number of grazing or mechanical harvesting methods.

In a forage based farming system, major components include the land base or soil, various crops grown, equipment used to establish and harvest crops, storage and processing facilities, and often animals. These components are linked by material and nutrient flows, the timing of activities, labor availability, cash flows, etc. Farm inputs are received from suppliers such as the agricultural chemical and machinery industries. The farm is also linked to outside, exogenous forces such as weather which influence production. Outputs are normally in the form of marketable crop or animal products. The farm may also contribute both positive and negative effects on the environment through aesthetics and pollution.

Because of the complexity, forages produced in farming systems must be evaluated with a systematic approach. All aspects of crop production and use must be viewed in relation to one another. This approach normally leads to modeling. Models can range from pictorial diagrams and simple accounting procedures to complex numerical models that simulate farming systems on a computer. Modeling of forage systems has advanced with the development of computers. Comprehensive models available today provide excellent research tools that enable better understanding of the role of forages in farming systems. In the future, these models also may be used for better management of forage systems.

Forages are either produced as a marketable crop in a cropping system or they are produced and consumed on the same farm in an animal production system. Each of these production systems will be discussed. This discussion will include the major components, important linkages among components, interactions between the farm system and its environment, and forage system models.

FORAGE IN CROP PRODUCTION SYSTEMS

In a crop production system, forage is grown and sold as a marketable product in conjunction with other crops. Most forage is marketed as animal feed, but opportunities exist for other uses such as industrial processing and biomass energy. Regardless of the end use, the same basic crop production system is used (Figure1). Forage is linked with other crops on the farm by their individual effects on soil structure and composition and the scheduling of operations according to available machinery, labor, and suitable weather.

Establishment and growth. Crop establishment normally requires a sequence of tillage and planting operations with inputs of fertilizer, pesticide, and seed. These requirements can vary widely dependent upon the establishment method with methods ranging from no-till frost seeding to a conventional tillage system requiring several operations (Vough et al., 1995). Given a similar method of establishment, requirements and costs for establishing forage are similar to those of other crops. For perennial forage crops though, input requirements and costs projected over a three to seven year stand life are considerably less.

Crop growth requires soil moisture and nutrients; lack of either during critical growth periods limits yield. Nutrients extracted from the soil must be replenished by chemical fertilizers or manure. In the case of legumes, nitrogen taken from the air can be fixed in the soil for use by the legume and other species growing in the forage crop (Miller and Heichel, 1995). When a legume crop is rotated to another crop, nitrogen available in the decaying plant material supplies substantial nitrogen to the new crop. The amount of nitrogen received varies with crop species, location, and crop management practices. For example, corn established on alfalfa land can receive about 100 kg/ha of nitrogen from the previous alfalfa crop. Proper use of legume forage can greatly reduce the need for nitrogen fertilizer input to the farm. The nutritive content or quality of forage varies among species with influences from crop maturity, fertilization, and environmental conditions (Buxton and Fales, 1994; Fick et al., 1994).

Harvest. Forage harvest requires a sequence of operations to mow, dry and retrieve the crop. Harvest inputs include machinery, labor, and energy. Machinery is a major cost in forage production, but this cost is often overlooked because it is not a direct cash flow to the producer. For an accurate analysis of forage systems, machinery requirements and costs must be appropriately apportioned among the farm enterprises. If machinery is not properly selected for the farm, machinery costs can be excessive exceeding the value of the harvested forage crop (Bartholomew et al., 1996). Labor requirements for harvesting forage with methods commonly used in North America range from 0.5 to 2.0 person h/t dry matter (DM) of forage produced. Energy or fuel requirements for these same methods are 4 to 13 L/t DM for typical dry hay systems and 9 to 23 L/t DM for wilted silage systems (Miller and Rotz, 1995).

Field curing is the most efficient and cost effective means of drying. Hay drying requires up to 7 billion joules of energy per tonne DM of forage (Rotz, 1995). The cost of this energy in the form of fossil fuels is at least three times the value of the crop. Dry matter and nutrient losses occur during field curing and each machinery operation. Harvest loss ranges from about 8% of the crop DM for typical wilted silage systems to 25% for dry hay systems (Rotz and Muck, 1994). Much of the lost material is highly digestible carbohydrate or highly nutritional leaves, so the loss in nutritive value is even greater. Much of this loss is converted to carbon dioxide, water, and heat through respiration and thus is lost to the surrounding air. A portion of the lost DM goes back to the soil adding organic matter and nutrients, but this is not a substantial contribution.

Storage. Forage may be sold directly after harvest, but often storage is used to improve the market for the crop. During storage, moisture and DM are lost, and this loss is directly related to the storage facility and methods used. Hay stored in a shed normally dries causing a 3 to 8% loss in weight. In addition, respiration will cause an additional DM loss of about 5% during a six-month storage period (Rotz and Muck, 1994). Most of the loss occurs during the first two months of storage, but a small loss continues during long storage periods. When hay is stored outside with less protection from the weather, hay remains at a higher moisture content which leads to DM losses of up to 30% (Rotz and Muck, 1994). Dry matter lost in storage causes a drop in digestible DM, an increase in fiber concentration, and a small decrease in protein content.

Forages may be stored, processed and sold as silage; however, most silage is used on the farm in animal production systems. For ensiling, forage is packed and sealed where anaerobic fermentation drops the pH of the crop allowing stable storage. Silage storage losses range from 6 to over 16% of crop DM, and these losses are primarily dependent upon how well the crop is sealed during storage (Rotz and Muck, 1994). These losses again greatly reduce the digestible DM and increase the fiber concentration in the forage. Another major loss is the breakdown of true protein to non-protein nitrogen which is less effectively used by the animal (Muck, 1987).

System inputs and outputs. A major exogenous force or input in crop production is weather. Weather influences crop growth, the timing of many production activities, and the DM and nutrient losses that occur during harvest. The most important weather parameters are solar radiation, air temperature, and rainfall. Photosynthesis and the resulting growth of the crop is primarily related to the level of solar radiation or light (Nelson, 1995). Solar radiation is also the major factor controlling the drying rate during field curing (Rotz and Chen, 1985). Crop growth increases with temperature between a base temperature and a maximum temperature, and these temperature limits are a function of crop species (Nelson, 1995). Field drying rate also increases with temperature and the associated increase in vapor pressure deficit (Rotz and Chen, 1985). Rain supplies soil moisture needed for evapotranspiration of the growing plant. Lack of adequate moisture creates plant stress, which reduces yield and affects the nutrient content of the crop (Halim et al., 1990). Rain during field curing can leach valuable nutrients from the crop causing up to a 50% loss in DM and a considerable loss in nutritive value (Rotz and Muck, 1994).

The primary output of a cropping system is the crop products produced. For forage, the output is most often dry hay, but it may be fresh or wilted hay, silage, or dry hay processed as cubes or pellets. The market value of the product is influenced by the processed form of the forage, the nutrient content of the forage, and the market demand for the product. On a regional or national scale, there is an interaction between the market and the quantity of material produced. When more forage is available than the market demand, the price will drop and vice versa. For the individual producer this relationship is less strong. The yield obtained on an individual farm is generally related to what occurs in the region, i.e. adverse weather normally effects large regions. Differences will occur though due to variations in weather, soil, and other cropping practices and the interaction of these factors. Forages are different from many other field crops in that they form a product with a lower value per unit volume. This limits transport distance, so forage price is more sensitive to a smaller market area.

Cropping systems also have undesirable outputs such as soil, nutrient, and pesticide losses to the environment. These losses occur when sudden or excessive rainfall events cause surface runoff to streams and nearby waterways. Excess moisture also leaches through the soil profile carrying some nutrients (primarily nitrogen) and pesticides into ground water. These losses represent externality costs to society. Quantification and analysis of externalities is an infant science, but procedures are being developed (Steiner et al., 1995). Costs for removing or restoring damage to the environment can represent a substantial increase over normal production costs. As externalities are better documented, future policy will likely require producers to bear a greater portion of their cost.

Forage crops are much less susceptible to soil, nutrient, and pesticide losses than row crops. An established forage sod improves water infiltration reducing runoff to as little as 1% of that obtained with row crops (Sharp et al., 1995). Sod also reduces the dislodging of soil particles by raindrops and it is more prone to capture soil particles flowing in surface water. Together these effects reduce soil erosion by a factor of one hundred or more compared to row crops. With reduced runoff and reduced soil erosion, soil nutrient losses are reduced proportionately. In addition, some forage crops may improve denitrification and water uptake to reduce nitrogen leaching (Sharp et al., 1995).

Modeling and analysis of crop production systems. Cropping systems can be evaluated and compared based upon a number of criteria. These include overall production, labor and energy efficiency in production, and effects on the environment. In most cases though, the primary consideration is economics. The value of the outputs of the system must exceed the costs of the inputs. Economic risk is another consideration. Production costs and profit will vary from year-to-year as influenced by weather and the market for products.

Modeling of crop production systems begins with the crop. Forage crop models have been developed for a number of crops and with a wide range in level of detail. Modeled crops include alfalfa, general or specific grasses, and pasture which includes both grasses and legumes. Models range from a single equation growth function (Cacho, 1993; Fick, 1984) to very complex sets of functions that describe the growth, physiological development, and nutritive content of the crop (Gustavsson et al., 1995). Simple growth functions are sometimes most appropriate for linking with larger system models when all that is needed is a prediction of yield over time. When used to study nutrient flows and their linkage with other crops, much more sophisticated models are required.

Current crop modeling work is focused on linking models of various crops with a common soil model to simulate cropping systems over several years of weather. Cereal and legume grain models are linked in the DSSAT (Decision Support System for Agricultural Technology) cropping system model to predict weather, soil, and crop management effects on nutrient flows and yield (Tsuji, 1994). The EPIC (Erosion/ Productivity Impact Calculator) model, designed primarily to study soil and nutrient loss from cropping systems, uses a general crop model that predicts yields for many crops including forage (Sharpley and Williams, 1990). APSIM (Agricultural Productions Systems Simulator) includes pasture models for the temperate, subtropical, and tropical areas of Australia (McCown et al., 1996). Cropping system models are needed which include a forage component that adequately predicts both yield and nutrient content of various forage crops. Cropping systems with this component are difficult to model because the yield and nutrient content of forage crops is much more dependent upon harvest strategy than that of other field crops.

Few modeling studies have evaluated forages in a cropping system with other field crops. This may largely be due to the lack of valid models available for this purpose. Such analyses are often based upon experimental data or farm surveys (Entz et al., 1995). Long-term studies needed to properly evaluate cropping systems are very expensive. There is much opportunity to use models validated with short-term field data to predict the long-term effects of cropping systems. As an example, corn and alfalfa models validated with two years of field data were used to determine that it was not feasible in the northern US to plant corn silage in a rotation following a spring harvest of alfalfa (Durling et al., 1996).

Biomass forage systems. At present, 3.5% of the US energy consumption is from biomass energy (Bransby, 1996). Most of this biomass comes from wastes, residues, and surpluses, but forage crops may have a significant role in the future. The major deterrent for use of forage as an energy source is the cost of production. In the US, forage production costs must be less than half their current market value for feasible use as biomass energy. Much of the production cost is in machinery and labor. Production costs can be reduced by spreading machinery costs over more harvested material. This can be done by selecting several forage varieties with different maturity dates to enable continuous harvest over a major portion of the year (Cundiff and Harris, 1995). The feasibility of biomass energy is also improved by increasing the conversion efficiency to more readily usable energy. Current research promises better conversion processes, particularly for forage sources. As the economics of biomass production and use improve over the next 50 years, new biomass sources, including forages, are projected to provide up to 18% of our energy needs (Brown, 1996).

The goal in producing forage for biomass production is a maximum DM yield with little concern for the nutritive or chemical content. This is quite different from the goal in producing animal feed. The most suitable crops for biomass production vary with climate. In warm temperate climates such as the central and southern US, switchgrass provides a good match to the needs in biomass production (Anderson et al., 1991). Legumes such as alfalfa may also have a role. Processes are under development for expressing high protein juices from the more fibrous portion of the plant (Koegel and Straub, 1996). The extracted protein can provide a high value product for human and animal consumption. The remaining biomass provides a lower value product that may be used as an energy source.

To better evaluate the role of forages in biomass systems, analyses with integrated cropping system models are needed. Only with integrated models can the interaction with other crops, weather, the environment and the market be adequately assessed. Further development and validation of cropping system models that include forage crops will enable this type of analysis. These models could be quickly adapted to various areas of the world to access the feasibility of using forages for biomass energy production.

FORAGE IN ANIMAL PRODUCTION SYSTEMS

Forage is often produced and used in an integrated farming system that includes animals. Major animal types are beef and dairy cattle, sheep, and horses. A few wildlife species such as deer and buffalo are also produced commercially for a small but growing market. Each animal type has different requirements, and these affect the interaction between the animal and other components of the farm. Despite the many differences, general relationships between feed production and animal use can describe the production system.

Animal feeding. Two general feeding methods are confined feeding and grazing. With confined feeding, animals are maintained in a facility, and all feeds including forage are mechanically harvested and brought to the animal. This approach is predominantly used for dairy and beef finishing operations in temperate climates. With grazing, animals harvest the forage, and they may or may not receive additional feed. Grazing systems are often used for cow-calf, stocker, and sheep production. In mild climates such as New Zealand, dairy farms depend on grazing for nearly all their feed needs. In colder climates of the northern US, Canada, and Europe, dairy and beef operations may use a combination of confined feeding and grazing. The components and processes of the two methods of production are quite different and thus require a much different model.

Animal production with confined feeding includes the crop production system described above along with feeding, animal, and manure handling components (Figure 2). Crops, particularly forage, are primarily produced to feed the animals. Excess crops are marketed, and supplemental feeds are purchased to meet the nutrient requirements of the animals. Major options for distributing feeds to confined animals include manual, total mixed ration, and individual computer feeding. Feeding is linked with other components of forage production by the form, particle size, and nutrient content of the forage. Supplemental feed must be properly combined with available forage to meet the animal's requirements. Total mixed rations blend all feed ingredients for a group of animals with similar requirements into a single feed ration (Muller, 1992). This method requires more energy but less labor input then manual feeding. Although computer controlled, individual animal feeders provide the ultimate control over animal diets, they are not widely used due to higher cost and little benefit over a properly used total mixed ration.

Animal nutrition. The major nutritional needs of forage consuming animals are protein, energy, and fiber. These nutritional needs are the primary link between the animal and feed production components of the farm. Different forms of protein have different value to the animal. Total forage protein includes unavailable, undegradable, and degradable proteins (NRC, 1989). Unavailable protein, that bound to plant fiber, is poorly digested and essentially unavailable to the animal. Undegradable protein resists breakdown in the rumen, and passes on to the intestinal tract where it is utilized. Degradable protein is rapidly used by microbes in the rumen. When integrating forage and animal production, protein needs of the animals must be matched to that available in the forage and supplemental feeds. Animals have different requirements of degradable and undegradable proteins dependent upon species, age, and stage of lactation (NRC, 1989). Forages vary widely in both total protein content and the fractions of unavailable, undegradable, and degradable proteins. These vary with crop species, stage of maturity, harvest losses, and harvest methods. For example, heating of hay during storage increases unavailable protein (Buckmaster et al., 1989) and ensiling increases the degradable protein fraction (Muck, 1987), both of which normally reduce nutritional value of the forage.

Animal production, particularly for meat and milk, is directly related to feed intake. The animal consumes available feed until either the energy requirement or physical fill is met (Mertens, 1987). Physical fill is related to fiber digestion. With rations high in forage fiber, particularly less digestible fiber, fiber digestion limits intake and the animal may not consume enough energy to meet requirements. If this occurs, production is limited. For growing and lactating animals with high energy needs, the proper balance of energy and fiber in the diet is critical to maintain maximum production. For other animals including most sheep and horses, the energy requirement is relatively low and easy to meet, so high forage diets can be maintained without limiting production or performance (Evans, 1995; Ely, 1995). Energy and fiber concentrations in forages vary with species and crop maturity (NRC, 1989). Within species, energy content and fiber concentrations tend to be inversely related. Harvest and storage losses also affect these nutritive characteristics. Plant components lost, particularly through respiration, are those high in energy and low in fiber (Rotz and Muck, 1994).

Manure handling. Animals produce large quantities of manure, which is often considered an unwanted byproduct. Manure is rich in nutrients required to grow crops with the major nutrients being nitrogen, phosphorous, and potassium. When the manure component is properly integrated with the crop component of the farm, it can be a valuable component of a sustainable farming system. Manure nutrients must be well utilized by crops to reduce nutrient loss to the surrounding environment. Up to half of the nitrogen in fresh manure can be lost through volatilization. Volatile nitrogen is lost in the barn, during storage, and following application until the manure is incorporated into the soil (Borton et. al, 1995). Loss of other nutrients is low, occurring primarily with surface runoff.

Manure is also linked with crop production components by available time and labor. When scheduling farm operations, manure handling can compete with tillage, planting, and harvest. Manure handling methods include accumulation in a dry lot, daily hauling and spreading on cropland, and long-term storage in a tank or pond. With dry lots, manure accumulates on a relatively small area; much of the nitrogen is lost through volatilization, and other nutrients are leached into the soil under the lot or carried away in surface runoff. Manure nutrients are not well utilized and the potential for degradation of the surrounding environment is great. When manure is surface spread daily, incorporation into the soil is delayed; thus much of the nitrogen and some other nutrients are lost. Due to these losses and a less uniform application of manure, nutrients are less accurately accounted and often ignored when determining fertilizer requirements. Although long-term storage systems are more costly (Borton et al., 1995), they are promoted in North America and Europe to better utilize nutrients and reduce loss to the environment.

Grazing. When forages are grazed, the animal component is more closely linked to the crop component (Figure 2). Animal performance is directly influenced by the quantity and nutritive value of available forage, and manure nutrients are directly recycled back to the soil. Although there are fewer components, processes involved are quite complex. The farm manager has less control over animal diets, so production becomes more difficult to predict. More manure nutrients, particularly nitrogen, are returned to the land by grazing animals, but these nutrients may not be used as efficiently. More nutrient loss occurs when the manure is not incorporated, and manure is not uniformly distributed by the animals (Gerrish, 1993). Thus, more fertilizer may be required, particularly in multiple crop systems. Crop yields are likely reduced compared to harvested forage, but with the elimination of harvest and storage losses, a similar amount of feed is available and the nutritive value is greater.

There are several approaches that can be taken to manage grazing animals (Matches and Burns, 1995). A system popular in New Zealand requires the lowest input. Animals are grazed on well-managed pastures with little or no supplemental feed. The protein, energy, and fiber contents of available pasture limit production. Animals calve in the early spring, so the animal's demand for forage corresponds to production potential of the crop throughout the year. Many animals can receive most or all of their feed needs while grazing, but fast growing and high lactating animals need protein and energy supplements to maintain high production. Concentrate supplementation can be added to better meet these requirements and thus increase production. In colder climates, confined feeding may be supplemented with grazing during the growing season to reduce feed costs.

Modeling and analysis of animal production systems. Much work has focused on modeling and analysis of forage crops in animal production systems. This work has studied either grazing systems or conserved forage systems with little work including both options on the same farm. Grazing models primarily have been applied to beef production in the US, UK, and Australia. Conserved forage system models have been developed to study dairy production in the US, Canada, and Northern Europe

The simplest grazing models link several relationships describing forage production and animal intake to predict animal production for a typical weather year (Dowle et al., 1988). With a little more complexity, linear program models simultaneously solve a series of equations describing beef or sheep production systems for average or typical weather (Pannell, 1995; Teitzel, 1991). These models have been used to evaluate the effects of a number of crop, animal, and economic management decisions. In MUDAS (model of an uncertain dryland agricultural system), a linear program model was extended to evaluate the effects of climatic risk over a range of weather years (Kingwell and Schilizzi, 1994). MUDAS provides a tool for identifying farm management changes and profits that result from incremental changes in pasture production in Western Australia.

More comprehensive simulation models of grazing systems were developed in the US. These models follow the crop growth, grazing, and animal production processes through time to study the performance and economics of beef production. Daily weather data is used to drive the processes over many years of weather. . SPUR (simulation of production and utilization of rangelands) is a physically based, rangeland simulation model (Wight, 1983). GRAZE uses a similar approach to model intensive beef production in more humid climates (Loewer et al., 1987). GRAZE provides a general model for evaluating and comparing the economic benefits and risk of beef animal grazing systems (Parsch and Loewer, 1987).

Some of the simpler conserved forage system models have used linear program and constrained maximization techniques to model dairy farms. With this approach, the impact of several farm management decisions were determined (Westphal et al., 1989; Doyle et al., 1991). A relatively simple simulation model of a dairy farm was developed to study the impact of several technological changes for a typical weather year (Lovering and McIsaac, 1981). This led to the development of more comprehensive models which simulate forage growth, harvest, storage, and use over many years of weather. Models developed in Europe used grass based forage systems alone (McGechan, 1990) or in combination with wheat (Doyle et al., 1990). A model developed in the US (DAFOSYM, the dairy forage system model) used alfalfa and corn crops in an integrated farming system (Rotz et al., 1989).

These comprehensive models provide more general tools for evaluating and comparing the performance and economics of various technologies and management strategies for dairy farms (McGechan and Cooper, 1995; Rotz and Gupta, 1996). The DAFOSYM model has been used to evaluate a wide variety of technology including: maceration and mat drying of forage (Rotz et al., 1990), hay storage methods (Harrigan et al., 1994), direct-cut silage systems (Rotz et al., 1993), and grazing systems (Rotz, 1996). Recent work has evaluated manure handling systems and their interaction with tillage and feed production operations (Borton et al., 1995).

Few models or analyses have integrated grazing and conserved forage systems. A general farm economic model, FLIPSIM (the farm level income policy simulator) was used to compare the economics of dairy farms with various cropping systems including conserved and grazed forage (Elbehri and Ford, 1995). DAFOSYM also includes a grazing option that can be used to evaluate rotational grazing of dairy herds along with confined feeding (Rotz, 1996). A more sophisticated model is needed to provide a general tool for evaluating a variety of grazing systems in conjunction with conserved forage systems for both beef and dairy production.

FUTURE NEEDS AND IMPLICATIONS

For proper evaluation of the role of forages in farming systems, comprehensive models are required to integrate the many components and interactions within the system and between the system and its environment. Models serve three major functions: research, teaching, and management aids. Each of these functions has different goals or requirements, which generally prevent one model from serving all three functions. Until now, most forage system models were developed and used as research tools to generate information on forages in integrated farming systems. Opportunity for further development of these research aids exists. Major areas for more work include 1) integration of forages in cropping system models that evaluate production benefits along with externality costs to society, 2) integration of more crop options along with forages in animal production system models, and 3) integration of grazing and conserved forage systems in a more comprehensive animal production model.

Teaching aids are models that can be used alone or in a classroom or workshop to illustrate the complexity of the production system and the impact of technological or management changes. Research aids provide good teaching aids if the effort is given to creating models that are easily used by others. Few models have taken this step, but this is likely to change over the next few years. Computer technology is now available for developing extensive, but intuitive, user interfaces for models. An example is the recent release of DAFOSYM for a Windows operating system on personal computers (Rotz and Gupta, 1996). More models will develop to this level to provide useful teaching aids.

Many models were developed with the promise of providing management aids for producers, yet few have reached this level of practical application. Comprehensive models that provide good research tools are generally too complex for application by a general audience. Although a good teaching aid can provide useful information for decision making, training of the user is required to insure that the model is used properly and thus provides reliable information. Management aids that integrate forages in farming systems will be developed in the future, but these may not come quickly. A different modeling approach such as an expert system is needed where comprehensive models or information generated by those models are used as experts in the decision making process. Expert system models are now used in forage crop management (Rykerd et al., 1993), but more development is needed for comprehensive management of an integrated multiple crop and animal production system.

Information gaps still exist for the development of all three types of models. More research and development work is needed to fill these gaps. This begins with the crop. Most available forage crop models do not adequately predict developmental stages of the growing plant and the effect of stage on nutritive content. Fundamental information on developmental staging is particularly lacking for many grass species. Much has been learned about the impact of harvest and storage on forage crops in recent years, but certain areas still need more information. Losses and changes in major nutritive constituents are well documented, but little study has been given to more minor nutrients such as vitamins and minerals. We now know that microbial populations on the crop can play a major role during storage. More information is needed to predict populations of various microbes as the crop enters storage and the effect they have during storage. This is particularly true for ensiled forages.

Much more information is needed to better predict forage utilization by ruminants. Available animal models perform adequately when predicting intake and performance for well balanced animal diets. There is a growing need to be able to predict intake and performance when the availability or nutritive characteristics of feeds is limiting animal response. This is particularly true under grazing conditions where animals tend to select plant material. Feed supplements are often not available, so animal response is a function of the quantity and nutritive content of the forage consumed.

The recycling of manure nutrients is another area where information is lacking. The production of manure nutrients can be predicted with reasonably good accuracy based upon a mass balance of the animal. Information is primarily lacking on nutrient losses during handling and application, and the transport of nutrients through the soil profile. Nitrogen is one of the more important nutrients, but one of the more difficult to track. A large portion of manure nitrogen is in the form of ammonia, which is very volatile. Information on the effects of environmental factors on ammonia volatilization is limited. Phosphorous and potassium are more stable, but more information is still needed on the transport and availability of these minerals. A relatively new and unexplored area of need is in quantifying the effects of farm losses on the environment and the societal cost for dealing with those effects.

The opportunity is great for further research on forages in cropping systems. Opportunities include basic and applied research on system components as well as modeling and analysis of complete farm systems. Regardless of experience and training, those with an interest in contributing to the effort of evaluating forages in cropping systems can find a place to apply their expertise.

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Figure 1
Forages in a crop production system interact with other crop production components to produce a marketable forage product.

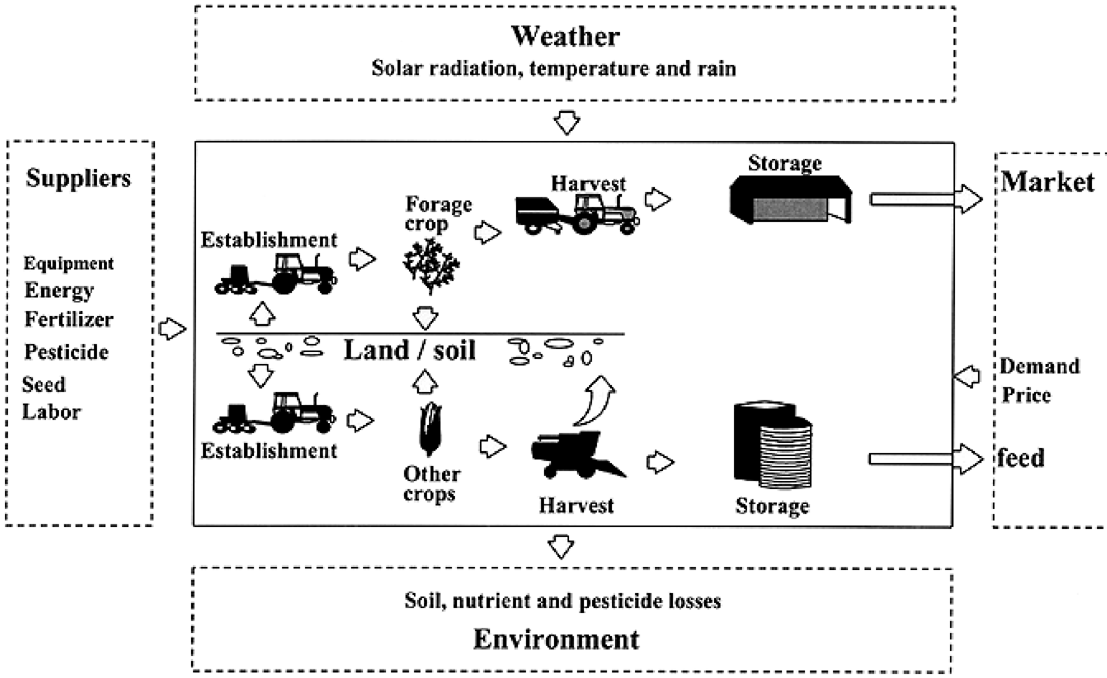

Figure 2
Forages in an animal production system interact with other crop components, animal components, and the environment to produce marketable animal and feed products.