Perspectives for livestock on grazinglands

W. Pittroff, T. C. Cartwright[1] and M. M. Kothmann[2]

Department of Animal Science, University of California, Davis, CA 95616, U.S.A.

ABSTRACT: There is growing concern about the negative environmental impact of livestock production. Recent studies funded by major donor institutions indicate a dramatic increase in demand for livestock products in the future, suggesting that the development potential of intensive livestock systems will be commensurate with the expected demand increases, with no negative consequences for food security of the poor and the environment. However, an analysis of technology options, current research policies in livestock production science and resource monitoring and protection technology supports the conclusion that output increases required to meet expected livestock product demand increases are unlikely to be achieved without negative environmental effects. If research and development policies are not adjusted, either environmental conservation or food security of the poor may be affected.

Key words: Livestock development, environmental impact, livestock production.

 Arch. Latinoam. Prod. Anim. 2002. 10(2): 133-143

Perspectivas para la ganadería a pastoreo

RESUMEN: En los últimos años la preocupación por el impacto ambiental de la producción ganadera ha dominado las políticas de investigación e inversión en el desarrollo ganadero. Estudios científicos de reciente publicación financiados por instituciones donadores internacionales predicen un aumento considerable de la demanda de productos ganaderos en el futuro. Al mismo tiempo se sugiere un potencial de desarrollo, especialmente en sistemas intensivos de producción, capaz de satisfacer estas futuras necesidades sin afectar la seguridad alimenticia del sector de la población con menores recursos económicos, o el medio ambiente. Sin embargo, un análisis de opciones tecnológicas, políticas de investigación, y tecnología disponible para el monitoreo y la protección de los recursos primarios justifica la conclusión que las proyecciones de aumento de producción que en la actualidad dominan la discusión no parecen realistas. Consecuencias negativas serias, o para el medio ambiente, o para la seguridad alimenticia, son posibles.

Palabras clave: Desarrollo ganadero, impacto ambiental, producción ganadera

Introduction

Three issues currently dominate research and policy for livestock production: food safety, environmental impact, and increase of demand. They are interrelated, and have complex ramifications for livestock producers, scientists, and policy makers.

We attempt to develop a synopsis with emphasis on livestock production on grazinglands. Throughout the text, the terms grazinglands and rangelands are used interchangeably.

Demand Projections, Trade and Market Perturbations

From the 1950's, onwards, world meat production has risen rapidly to more than 233 million tons in 2000 (Figure 1). Increases in meat consumption are driven by higher available incomes because meat is a commodity with appreciable income elasticity of demand. As affluence is currently increasing in the most populous countries, one might expect further, even dramatic increases in global demand for meat. Figure 2 indicates the rapid increases in meat consumption observed in the developed Asian countries, as op-

Recibido Abril 1, 2002. Aceptado Mayo 9, 2002
E-mail: wpittroff@ucdavis.edu

[1]Department of Animal Science, Texas A&M University, College Station, TX 77843, U.S.A.

[2]Department of Rangeland Ecology and Management, Texas A&M University, College Station, TX 77843, U.S.A

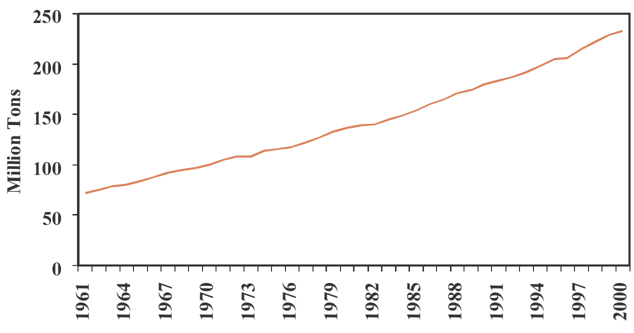

Figure 1. World meat production (in millions of tons per year).

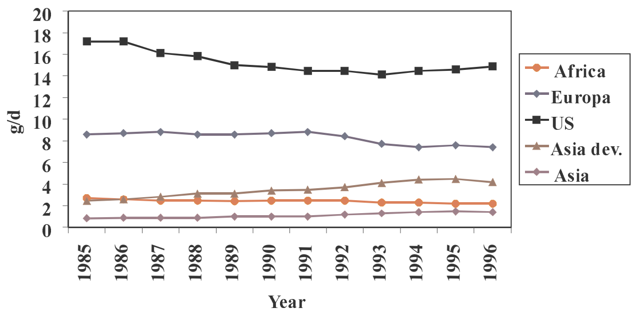

Figure 2. Meat per capita protein consumption from meat.

posed to other parts of the world. Indeed, the International Food Policy Research Institute (IFPRI) presented a document (Delgado *et al*., 1999) entitled: "Livestock to 2020: The Next Food Revolution", predicting demand increases that, if not met with concomitant increases in production capacity, may lead to dramatic market perturbations and serious food security consequences for the poor. In their description of the potential problems associated with the expected expansion of livestock production, the authors adopted an optimistic position in regards to the feasibility of production increases. This is perhaps best illustrated by the fact that in the macro-economic model used by IFPRI (Delgado *et al*., 1999), *Yield* (in livestock production) at time *t* is a simple, monotonically increasing function of *Yield* at time *t-1* (Rosegrant *et al*., 1995). In a subsequent section we will examine the validity of such assumptions.

Meat trade statistics (Figures 3, 4 & 5) suggest that trade policies are strongly influenced by national interests governing the structure of the national or regional rural sector. For example, the European Union (EU) is both the world's largest exporter and importer of beef. This is not surprising given that due to market interventions, the EU frequently accumulated large stockpiles of beef that had periodically to be disposed of. Thus, the Common Agricultural Policy (CAP) of the EU has led to world beef market perturbations caused by the offering of beef far below real production cost. In the wake of the BSE crisis, however, it is becoming clear that such interventions are not sustainable. On the other hand, when examining the import quotas of four countries allowed to export into the U.S. (Figures 4 & 5), it is apparent that such quotas, when expressed in terms of production capacity, are more reflective of strategic significance (for the United States) of the exporting country than of equitable trade terms.

Such data are relevant because developing countries are expecting to participate more strongly, and perhaps on more equitable terms, in the world agricultural market in the future. In order to develop realistic policies, they must be aware that it is unlikely that trade terms will ever be free of political considerations. Higher meat imports into the EU, for example, are possible. The European cattle industry is currently suffering from a catastrophe from which it might never completely recover, in particular because of the fundamental changes in agricultural policy (towards extensification of production systems) some countries in Europe are initiating. However, the dependability of these market opportunities may be less than expected, as is evidenced by the current disagreement regarding the regulation of meat meal in animal feeds. One would expect that the meat meal ban would be indefinite; however, apparently special interests have influenced national governments in Europe to adopt a position that may be detrimental to consumer safety and producer sustainability by moving to reestablish the use of meat meal in animal feeds. This decision contradicts extensification efforts, and is indicative of the importance of clientele-oriented politics in market and trade policy. It is sometimes not obvious who that clientele is. In any case, livestock producers should understand the concerns of their customers, and employ production technology acceptable to them. Often they do not.

Standing in the way to more success in world trade for developing countries are two major obstacles: (1) the dismally low levels of public and private investment into agricultural research in developing countries, and (2) the lack of knowledge of market conditions and requirements by many decision makers in developing countries, in particular those that already have the infrastructure to successfully compete now, such as Brazil and Argentina. Further, there seems to be little awareness of the fact that the ecological and social conditions associated with the production of livestock are major factors in consumer acceptance. For example, cattle producers in Colombia, after declaration of an area of the country to be free of Foot and Mouth Disease, are now hoping to export into the EU. They will be disappointed to find that meat produced on land from which peasant farmers were forcibly removed may not be an acceptable commodity in Europe.

Whether or not the United States will more strongly participate in the world meat trade in the future is open to debate. It seems that the U.S. beef industry missed a historic opportunity to take advantage of the European BSE crisis at

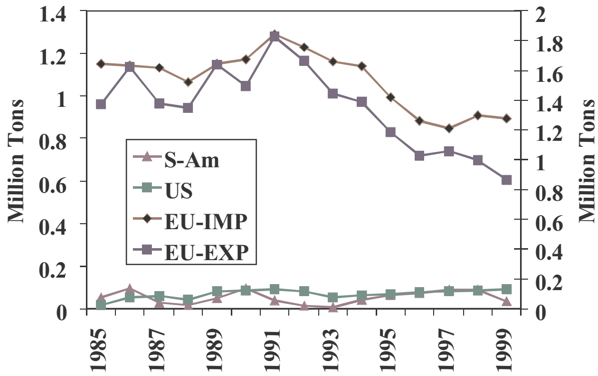

Figure 3. Annual beef exports by South-America, USA, and EU, and beef imports by the EU (right axis).

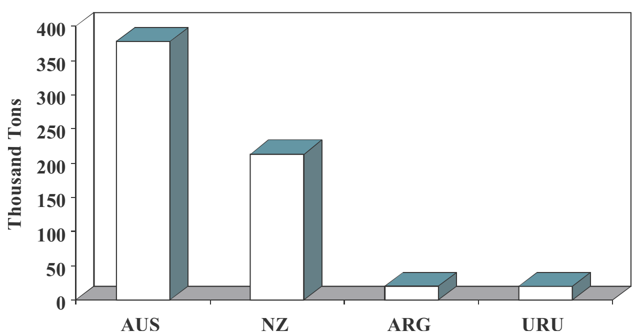

Figure 4. U.S. import quotas for four selected countries (Source: USDA-ERS).

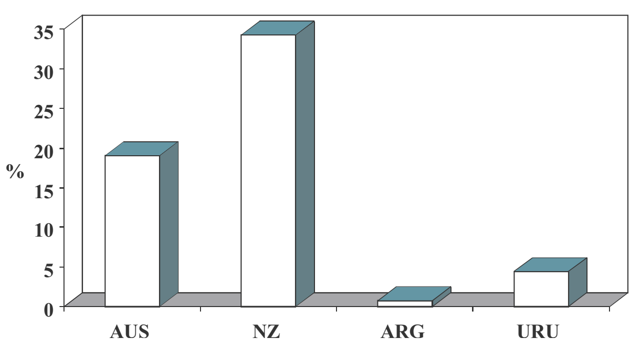

Figure 5. U.S. import quotas for four selected countries in percent of their production capacity (Source: USDA-ERS; FAO).

a time when the price differential on the retail level between the two regions would have allowed for substantial profits. U.S. trade negotiators insisting on the approval of steroidal growth promoters by European authorities in beef exported to the EU have probably damaged the public perception of U.S. beef in Europe for a long time to come. Without doubt, this position indicated a profound lack of understanding of the European market, and the own industry potential. One might conclude either ignorance or lack of interest in increased world market participation as the reasons for such behavior. As will be discussed below, the potential to increase meat production levels in the U.S. may be limited in the future; thus, the increases in livestock production projected by IFPRI may have to occur mostly in developing countries.

BSE, consumer concerns about growth promoters, and the recent European Foot and Mouth crisis suggest that global market integration may create opportunities, but definitely increases vulnerability to crises quickly transcending regional boundaries. Only intimate knowledge of the global market will allow sensible contingency planning. The industry must be aware that common sense may not always govern policy, as clearly exemplified by the European BSE crisis, and the European decision to abandon vaccination programs in hope of rather marginal export opportunities.

Environmental Impact of Livestock Production and the Effects of Technology Development

Intensive systems. The study by IFPRI (Delgado *et al.*, 1999) on projected demand for livestock products also considered the environmental impact of livestock production. This discussion was largely based on a multi-donor analysis on the effects of livestock production on the environment (de Haan *et al*., 1997). Delgado *et al*. (1999) and de Haan *et al*. (1997) focused in their assessment of the positive environmental effects of livestock production on the integration of crop and livestock production. Such positive effects (improved nutrient management, more efficient use of land and water resources, maintained soil fertility, availability of draft power) undoubtedly exist, but are manifest only in farming systems unlikely to contribute substantially to the 'revolutionary' increase in productivity required to meet future demand for livestock products. High increases in productivity in both crop and livestock production occurred during the past 40 years in those farming systems that are either crop or livestock systems, but not in integrated systems. De Haan *et al.* (1997) pointed out that the trend to concentrate livestock production in industrial complexes is continuing. By 1997, almost 45% of the global meat production occurred in industrial systems. These systems are termed 'open' systems, i.e. they depend on the outside supply of cattle, feed, energy, labor and other inputs. By necessity, such systems critically depend on the availability of cheap energy, both directly, and indirectly by their dependence on feed crops. It is in these systems that limits to growth are apparent in many developed countries. Since the 1974 energy crisis, much of the discussion on limits to growth has focused on energy cost and availability. However, water resources begin to emerge as the potentially more acute limiting factor in agriculture. Postel (1999) calculated that the number of people living in countries experiencing acute water stress (water availability less than 1,700 m^3 per person per year) will increase from 467 million in 1995 to more than 3 billion by 2025. Water stress is generally discussed in the context of *available water*, and thereby it is overlooked that water *quality* is an issue of equal significance. In the context of livestock production, it may be the most relevant production constraint in developed countries. The model calculations by Delgado *et al*. (1999) projected that an additional 292 million tons of cereals will be required as feed by 2020, with a minimal impact on grain prices. This prediction implies that the trend of falling grain prices, which began in the mid 1990's, continues – but this is impossible if the current requirement of 1000 tons of water for the production of 1 ton of grain (Postel, 1999; Postel, pers. comm..) is not substantially reduced. Even without an exhaustive discussion of the numerous other negative environmental impacts of intensive livestock production, it may be concluded that the developed world requires very fundamental advances in production technology just to *maintain* current production levels in the livestock industry – further increases seem to be unrealistic. However, if excess nutrient production (a problem closely associated with water and soil quality) is added to the equation, limits to increases in production in the developed countries become abundantly clear.

De Haan *et al*. (1997) suggested a number of policy and technology options to reduce excess nutrient loading originating in intensive livestock systems. The only suggested technology option that a priori would *not* lead to a reduction in productivity is the development of improved feeding systems. However, it is currently virtually impossible to obtain research funding for the development of improved feeding systems that would reduce excess nutrient output. One of the possible reasons is that expected progress is necessarily slow. This contrasts starkly with the expectations generated by molecular genetics, which seem to have created the perception that transgenic animals may be capable of resolving most if not all current troubles in livestock production. We conclude:

1. Limits to increases in livestock production in the developed world are obvious. Water and energy requirements, and direct point and non-point pollution have already initiated wide-spread attempts at extensification.
2. The increases in feed grains required to sustain the rapid expansion of livestock production needed to cope with expected increases in demand do not seem to be achievable, primarily because of increasingly limited availability of water.
3. Specific technology required to mitigate the negative environmental impact of intensive livestock production at current production levels is currently not under development.

It seems to be relevant to cite one of the key conclusions of the Report of the BSE Inquiry, commissioned by the British Parliament (Anon., 2000, p. XVII): "BSE developed into an epidemic as a consequence of an intensive farming practice – the recycling of animal protein in ruminant feed. This practice, unchallenged over decades, proved a recipe for disaster." Thus, limits to intensification may become apparent in many different ways.

Extensive systems. IFPRI (Delgado *et al*., 1999) stated clearly that the increased demand for livestock products can only be met by industrial systems. The reasons given include reports on the degradation of the primary resource of extensive livestock systems, grazinglands, and the inherent low productivity of these systems. Furthermore, in many parts of the world, cropping systems are encroaching on marginal lands, thereby reducing available suitable grazing and increasing degradation by increased use of lands not suitable for any than very light stocking rates.

UNEP (1992) has suggested that about 20% of the world's grazing lands have been degraded. The extent of degradation and 'desertification' is debated (Skarpe, 2000), but trends from US rangelands indicate that degradation of range resources caused by changes in vegetation composition, primarily brush encroachment and invasive weed infestation, can be very substantial. It is not contested that the primary reason for the reduction in primary productivity is the human activity of grazing management – a standard European textbook (Klapp, 1971) stated that all forms of livestock grazing may eventually lead to a reduction in primary productivity. Thus, we observe currently two simultaneous processes that contribute to the reduction of the productivity of grazinglands: reduction of available area, primarily by crop production, and deterioration of primary productivity of the remaining grazinglands. It is important to emphasize that we understand 'productivity' as the production of usable nutrients for livestock.

In the developed world, primarily the U.S., urbanization and rapidly increasing change of ownership of lands traditionally used in ranching systems substantially contribute to the reduction of lands available for extensive livestock production. For example, much of the ranch lands have been and continue to be lost in the state of California (Huntsinger *et al*., 1997), which once was an important resource for sheep and beef production.

Figure 6 shows that the number of cattle increased in both Africa and South America (selected countries), while remaining constant or declining in developed countries. Given constant exports from South America, increased production was largely absorbed in domestic markets (Figure 7). However, the potential for future development is much more limited in Africa than in South-America, because of human population pressure and substantial natural barriers (in particular trypanosomiasis) to livestock production. Thus, a discussion of technology options for extensive, grazinglands-based livestock production is needed, even more so when considering that the development potential of intensive systems may be much less promising than suggested in the IFPRI (Delgado *et al*., 1999) report. De Haan *et al*. (1997) in their section on technology options for extensive grazinglands do not offer anything. This rather bleak outlook does not suggest reason for optimism. If livestock offtake from grazinglands cannot be stabilized or increased, increasing demand for meat and milk must be expected to have rather serious consequences for the food security of those without means to cope with the increasing prices that must ensue.

Livestock Technology for Grazinglands

Productivity increases in the livestock sector in the developed world after WW II were driven by rapid advances in quantitative genetics *and the concomitant improvements in the feeding environments of livestock.* Hammond (1947) formulated the principle governing genetic selection programs aimed at maximizing production (although this principle is questioned under certain circumstances it appears to be relevant here): “In general, variability in quantitative characters is greatest under good nutritional conditions”. This statement is of course correct for single yield traits, and without doubt, increases in milk and pork production in intensive systems have been nothing less than spectacular. However, such successes have been largely absent from extensive systems. Attempts to transplant technology from intensive livestock production to extensive systems have invariably failed. It is, therefore, in order to discuss the production technology constraints relevant to livestock production on grazinglands.

Genetics. Livestock production science seems to be currently dominated by tremendous investments in research and technology for the identification of individual genes responsible for performance traits. A thorough analysis of the technical basis and promises of ‘livestock genomics’ and its various semantic derivatives (‘proteomics’, ‘phenomics’) is definitely an urgent need, but beyond the scope of this paper. We suggest a commentary by Weiss and Terwilliger (2000), and the excellent review by Holtzman (2001) as further reading; although both papers focus on genomics of susceptibility to common diseases in man, their discussion is highly relevant to genomics applications in livestock. While transgenic animals are seldom stated as the final objective, it is of course logical to assume that they play a major role in research planning. Consumer acceptance of transgenic crops is not generally enthusiastic, in particular in Europe, and it has not even been tested on animals as none have entered the food chain yet. However, the broader question relevant for our discussion is: can livestock modified at the individual gene level improve offtake from extensive systems? In such systems, low production per animal (slow growth, low milk yield) is at the system or herd level compounded by low fitness. The generally harsh grazing environments in which ruminant stock undergoes yearly cycles of weight gain and loss do not allow high levels of reproduction. The most important goal in such systems, therefore, is to improve reproduction. This is a complicated undertaking, however, because yield traits may

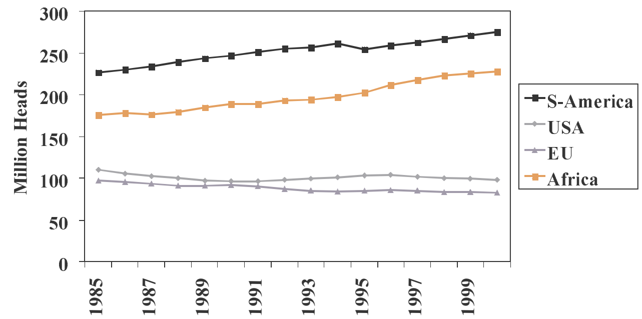

Figure 6. Cattle inventory (South-America only Argentina, Brazil, Colombia, Uruquay and Venezuela (million heads; Source: FAO).

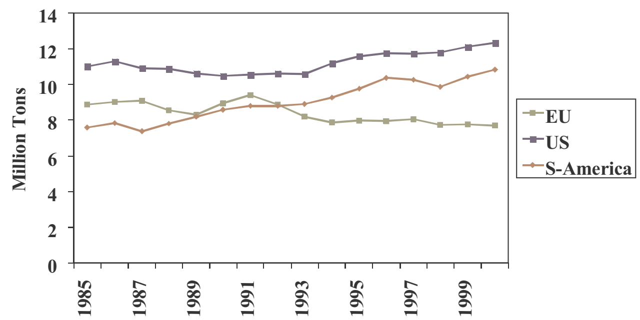

Figure 7. Meat production (South-America only Argentina, Brazil, Colombia, Uruquay and Venezuela (million tons; Source: FAO).

have negative phenotypic correlations with fitness traits even when the genetic correlation is zero (Baptist and Carles, 1989). For example, it might be desirable to attempt to increase weaning weight by selecting for cows with higher milk production potential. Without concomitant provision of the higher nutrient levels required to sustain increased milk production, depletion of the energy reserves of the mother cow will be more extensive, and reproductive success reduced. The economic effects on the herd level of such interactions are complex and not easily amenable to pen and paper exercises (more discussion on this matter below), but it is clear that fitness can have pervasive effects on system performance.

Fitness traits are generally characterized by low heritability. This is not surprising given that natural populations, or populations in relatively stable environments, have probably reached a selection limit for fitness traits. However, since genetic variability continues to exist, it can be inferred that the genetic variance of fitness traits is due to dominance and epistatic interaction effects. On theoretical grounds selection for yield traits must be expected to reduce fitness (Falconer, 1989). Thus, fitness may be expected to respond to selection only if the environment changes, because then the array of gene frequencies for fitness traits in the population is no longer the best. However, extensive grazing systems are characterized by the lack of feasibility of permanent improvement of environmental conditions. Since fitness is of such pervasive significance, selection for production traits in extensive systems may be expected to be counterproductive (herd level offtake lower as a result of improved genetics for yield traits). Likewise, seedstock that was selected for superior performance potential under good conditions often changes rankings in more challenging environments. This phenomenon is called genotype–environment interaction, and has been shown to be of major importance in livestock development projects. In conclusion, the effectiveness of genetic selection in the improvement of livestock productivity in extensive systems must be limited as long as it is not possible to identify quantitative traits exhibiting additive genetic variance that confer superior *realized* performance. Clearly, this applies even more so to the applicability of molecular and transgenic genetic improvement methods. Fitness traits, being characterized by epistatic and (over-) dominance genetic effects, cannot be modified by the exchange or addition of single genes, nor is it conceivable that meaningful molecular markers for fitness traits may be identified.

We do not generally rule out that there may be some distant hope for an application of genomics in the identification of genes responsible for resistance to or tolerance of specific infectious diseases. However, the arguably most serious of specific infectious diseases (in terms of affecting the usefulness for cattle production of vast geographical regions), bovine trypanosomiasis, presents intricate problems not likely to be easily amenable to genomics approaches. There are obviously trypanotolerant cattle breeds, but trypanotolerance seems to be conferred by a combination of very different traits (clearance of parasites, control anemia, maintain intake). It is perhaps not surprising that a large project on the genetics of trypanotolerance seems to be behind schedule (Anom., 2001).

Nevertheless, there are animal genotypes performing better under harsh conditions than others. How can these differences be harnessed for the improvement of livestock production?

Research Priorities. Joandet and Cartwright (1975) suggested the following 5 priorities for research on beef cattle production systems:

1. The relationships between nutritional level, hormonal production and the onset of estrous cycling in heifers and postpartum cows.
2. The energetic efficiency of fat deposition, maintenance and mobilization for utilization.
3. The genetic variability of growth curve parameters.
4. The effect of ambient temperature, body composition and physiological state (especially weight loss) on nutrient requirements.
5. The effect of disease at sublethal levels on growth and reproduction.

These priorities were identified in the context of the development of mathematical models of ruminant production systems. Joandet and Cartwright (1975) argued that efficiency of beef production systems (exemplary for extensive livestock systems in general) is a function of factors traditionally studied (separately) in nutrition, physiology, genetics, range and forage sciences, production economics and marketing. Therefore, a scientific method conducive to effective *integrated research* of these multiply interrelated factors is required to achieve progress. This method, systems analysis and mathematical modeling of animal production systems, has produced a range of bio-mathematical models, some of which have been widely used in the analysis and planning of livestock systems (Blackburn and Pittroff, 1999).

A meaningful mathematical production system model designed to simulate system function based on the representation of biological processes and events requires functional understanding of the biology incorporated in the model. Clearly, the knowledge gaps identified by Joandet and Cartwright in 1975 have not been addressed successfully to date. As a result, we presently do not possess functional understanding of important elements of genotype – environment interactions relevant for livestock on grazinglands. In other words, even if effective genetic selection methods were available, we would not know what to select for. When viewed in the context of the apparent limitations to progress by using genetic improvement methods, it transpires that perhaps a better ability to strategically (by selection of appropriate breeds) and tactically (by improved herd and nutrition management) cope with genotype – environment interactions holds the key to increased production levels on grazinglands. In order to achieve this ability, important basic biology, including the five points outlined by Joandet and Cartwright (1975), must be understood and translated into (mathematical) decision support models.

Nutrition Resources. Appropriate decision support models do not only require the understanding of animal biology, they also must be supplied with reliable data on the nutritional quality of feedstuffs available to grazing animals. In extensive grazinglands-based systems, knowledge about nutritional resources is perhaps the most limiting factor. We currently do not possess reliable quantitative descriptions of the nutritional value of most grazing resources. Without knowledge about available nutritional inputs, prediction of output is impossible. Investment into livestock development on grazinglands has traditionally suffered from uncertainty about the expected returns. Nutrient requirement prediction tables produced in developed countries (e.g., NRC, 1996; ARC 1980) of course do not reference most of the forage species relevant in grazinglands in developing countries. The need for appropriate quality values has been emphasized in particular for tropical forages (Zemmelink and ‘t Mannetje, 2002). However, these authors reduced their proposal for a better forage value assessment for tropical forages to the consideration of forage selectivity, i.e. the fact that ruminants, given enough forage on offer, are able to select a diet of acceptable quality due to the heterogeneity of tropical forage plants. However, the perhaps most critical shortcoming of current nutrient requirement systems is the fact that they do not consider animals undergoing periods of weight loss. Such major changes in nutrient requirements make it imperative to explicitly consider the interaction between animal requirements and forage quality. Only a dynamic, not a factorial model can accomplish this.

The prediction of available nutrient levels for grazing animals is an extremely complex task. Pittroff and Kothmann (2001a,b,c) identified conceptual and mathematical problems in an analysis of a large number of intake prediction models. Two aspects make prediction of nutrient intake in grazing animals particularly difficult: selectivity, i.e. the ability of grazing animals to choose plant species and plant parts, and effective nutrient quality of ingested feedstuffs in the grazing animal. Because ingested feedstuffs undergo massive transformations in the forestomachs of ruminants, proximate analysis of nutrient content and in vitro analysis by approximating techniques (for example, the Hohenheim Gas Test, Blümmel *et al*., 1997) can only supply information of limited generality. Lack of knowledge about nutritional quality also applies to many as of yet underutilized crop byproducts. Pittroff and Kothmann (1999) identified as the major theoretical obstacle to the development of better prediction models the fact that the current theory of intake regulation views nutritional properties of forages as the sole property of the forage proper. However, it is the result of the interaction between animal and feed (Illius and Allen, 1994). Therefore, without the explicit consideration of animal requirements, i.e. a measure of theoretical or potential requirements, and an iterative calculation of effective or realized requirements as they are determined by diet properties, it is not possible to reliably predict intake. Because nutrient requirements are dynamic, a dynamic model is required to accomplish this task. Pertinent research seems currently not to be under way, probably because important other knowledge gaps exist. For example, although yield level effects in ruminants of (a) synchronization of protein and energy supply to the host animal (Robinson *et al.*, 1997; Shabi *et al*., 1998), (b) protein – energy ratio in the diet (Fattet *et al*., 1984; Vipond *et al*., 1989; Sinclair *et al*., 1995; Witt *et al*., 1999), and (c) physical form of the feed (Reynolds *et al*., 1991; Lachica *et al*., 1997) have been clearly documented, pertinent research to obtain data suitable for a prediction model currently does not seem to be fundable.

Nutritional monitoring. As pointed out above, dynamic body weight change is one of the properties of extensively managed livestock on grazinglands. In order to cope with animals periodically entering catabolic state, nutritional monitoring is desirable. Supplementation is mostly not economically feasible for grazing livestock, but there are supplementation regimes enhancing the utilization of mature, nutrient-deficient forage. Strategic supplementation of animals may further prove to be instrumental in improvement of reproductive performance and maintenance of immune competence.

Nutritional monitoring of grazing livestock is obviously no trivial task. In recent years, the analysis of fecal samples by near infrared spectroscopy (NIRS) has gained acceptance as a tool to monitor nutritional status (Lyons and Stuth, 1992). The method is based on the hypothesis that the chemical composition of feces is a meaningful descriptor of the composition of the diet. It is, for example, used in monitoring programs sponsored by the United States Department of Agriculture for U.S. ranchers. The method relies on multiple regression models relating NIRS absorption spectra to chemical properties in calibration samples. As Figures 8 and 9 show, feeding situations exist where N content of the feces, for example, does not exhibit a meaningful relationship with N ingestion or absorption. This would be expected particularly in a situation where supplementation changes the proportion of digestible matter digested in the hindgut. Supplementation regimes changing rate of pas-

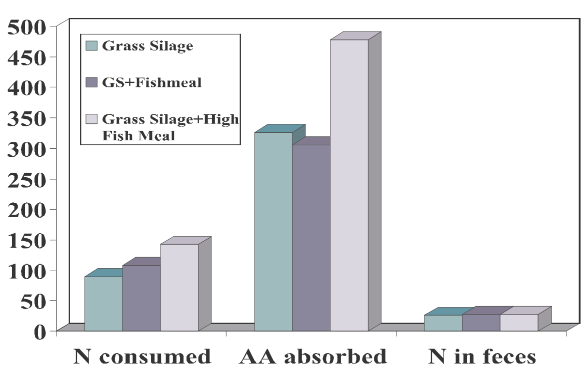

Figure 8. Nitrogen ingested and excreted (in grams per day) in feces and amino acid absorption (gram total amino acids per day) by cattle fed three grass silage diets with or without fish meal supplementation (Beever *et al*., 1990).

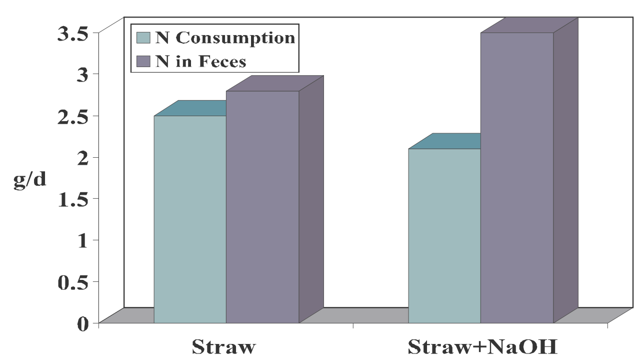

Figure 9. N excretion in diets with similar OM digestibility (Ørskov and Grubb 1978. Note: The original paper does not contain fecal N data. Ørskov (1992) cites these data on p. 88).

sage, not uncommon, might lead to shifts in sites of fermentation, thereby questioning the validity of calibration equations. A rigorous validation of the NIRS method employing multiply cannulated animals with quantification of production of fermentation products and nutrient absorption along the GI tract seems to be lacking.

Real time data on energy expenditure are theoretically a direct indicator of net energy intake. It is now possible to measure heart rate, which is directly related to energy expenditure, on free ranging ruminants. Oxygen consumption per heart beat (O_2 pulse) is a parameter relatively insensitive to level of energy intake (Brosh *et al*., 1998). Thus, heart rate measurements calibrated to O_2 consumption can potentially serve as a direct indicator of nutritional status. The technology to collect such measurements in real time with implantable devices already exists. However, important research questions must be resolved. For example, due to the effects of body tissue mobilization, the relationship between O_2 pulse and energy intake becomes unreliable at energy intake levels below maintenance, as might be expected. Therefore, the reliable estimation of energy intake by this method is restricted to above maintenance situations. However, for the purpose of nutritional monitoring, changes in heart rate rather than precise absolute measurements are relevant. Figure 10 (Aharoni *et al*., unpublished data) shows that heart rate patterns clearly reflect the level of energy intake in ruminants.

Nutritional environment, reproduction and immune competence. The discovery of leptin has opened new research avenues into the biological basis of genotype – environment interactions determining fitness traits, and consequently system level performance of extensive livestock production. Leptin plays a central role in the communication of energy status to the reproductive tract in mammals (Caprio *et al*., 2001) and is closely associated with adipose tissue mass (Friedman, 1998). We are currently researching the hypothesis that specific differences exist in the link between energy reserves and reproductive performance between San Martinero cattle, a Criollo breed, and Zebu cattle managed on pasture in the Eastern lowlands of Colombia. This hypothesis was generated by observations indicating that Criollo cattle have less difficulties maintaining reproductive performance under deficient nutritional conditions when compared to Zebu contemporaries. The possibility that such differences are manifest and can be functionally identified would seem to have important ramifications on the better understanding of the effects of genotype – nutritional interaction of extensively managed cattle.

Likewise, leptin has been found to be involved in the immune response (Samartin and Chandra, 2001). It activates components of signaling pathways from several cytokines. There is indication that leptin regulates macrophage function, and may alter TNF- and IL-6 production (Santos Alvarez *et al*., 1999). Besides leptin, adipose tissue produces other regulators involved in immunocompetence. For example, adipsin catalyzes the first activation step in the alternative pathway of complement (Samartin and Chandra, 2001). Research on the relationship between nutrition and immunocompetence is in its very beginnings for extensively managed livestock. However, there is sufficient evidence to indicate that such work could play a substantial role in the identification of genotypes with specific traits required for the adaptation to the harsh environmental conditions typically encountered in extensive, grazinglands-based livestock systems. The functional understanding of genotype–environment interactions in reproduction and immunocompetence may prove to be instrumental in stabilizing and increasing offtake from extensive livestock systems, as it may allow to considerably improve strategic and tactical management.

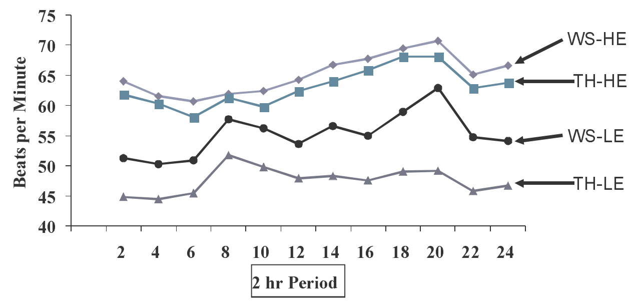

Figure 10. Energy intake effects on heart rate (average of 6 beef cows). WS: wheat straw; TH: tomato hay; HE: high energy supplement; LE: low energy supplement (Aharoni *et al.*, unpublished).

Grazinglands Condition and Trend

Agricultural policy makers and the general public alike frequently perceive livestock as a threat to the environment. Although pure speculation, one might argue that the images of African droughts depicting human skeletons on rangelands denuded of all vegetation by ostensibly ill-managed livestock have substantially contributed to this situation. On the other hand, many are convinced that clearing the rainforest occurs primarily in order to expand cattle production to feed the affluent. Without question, many rangelands are improperly managed, and rainforests are slashed to create cattle pastures. However, the current state and future trends of the world's grazinglands are unknown by any standard. This void may be as much the result of a lack of data as of the lack of consensus as to how to *interpret* existing data. This question is exemplarily illustrated by the first issue of volume 31 of the journal 'Ecological Applications', which was entirely dedicated to 'Herbivory and its consequences'. This issue documented the raging scientific debate about the effects of grazing on range/grazinglands ecosystems. It is beyond the scope of this paper to attempt to summarize this discussion. However, some important points will be addressed.

Ecological models of rangelands. Skarpe (2000) discussed how failure to consider long-term variability of rangeland condition contributed importantly to the idea that deserts were advancing at an alarming rate in Africa. The expansion of the Saharan desert in the 70's and 80's seems to have been the result of meteorological conditions much more than human related activities. In other words, ecological models suitable for the description of rangelands must find meaningful ways to deal with stability and resilience. Holling (1973) presented a theoretical discussion of the resilience vs. stability concept as it relates to ecosystems. Noy-Meir and Walker (1986) introduced the idea into rangeland ecology. It is no longer assumed that plant communities on rangelands move to one and only one stable state; rather, depending on weather regimes and management, rangeland communities may attain alternative states. Transition between these states may occur with different probabilities. As discussed by Westoby *et al.* (1989), circumstances allowing favorable transitions represent opportunities, and those threatening unfavorable changes constitute hazards. The most important consequence of this concept (the 'State and Transition Model') is that the objective of achieving an equilibrium condition of rangelands is considered futile, and that management must be flexible, striving to take advantage of opportunities, and avoiding hazards. This concept is of course incompatible with the concept of 'carrying capacity', as carrying capacity per se cannot be defined independently of the current state of the resource and management goals.

The more variable and unpredictable weather conditions are, the more relevant is the State and Transition model. This new concept, on the other hand, has important ramifications for the assessment of rangeland condition. If it can be no longer assumed that one climax community exists for a certain type of rangeland, then there is no standard against which to compare the current status. Rather, the current status would have to be compared to a condition compatible with management objectives, which may change over time. By necessity, this also invites discussion of the role of invasive species. Are exotic species detrimental to ecosystem function per se? If an invasive species has merely replaced an indigenous species, fulfilling the same function in the ecosystem (for example, making the same contribution to watershed function), it is hardly justifiable to classify the rangeland as inferior because an exotic species is present. Folke *et al*. (1996) emphasized that the most important aspect of bio-diversity is functional diversity. In managed ecosystems, ecosystem function can hardly be separated from management objectives. Johnson and Mayeux (1992) supported this assertion in their analysis of temporal stability in communities. They concluded that physiognomic structure and function seems to be more stable than species composition. Thus, classification systems for rangelands that are under human management (almost all are) should not use vegetation composition standards based on presence or absence of exotic species independently of their function for the assessment of condition. This, however, is currently the case for public rangelands in the U.S. and is one of the causes of ever increasing restrictions of their use for livestock grazing. As one of the consequences, it has led to the public perception of grazing invariably leading to environmental destruction. This public perception is so strong that further decreases in livestock production on U.S. rangelands are almost inevitable. Because of the importance of these lands for beef cattle production in the U.S. in general, negative effects on beef output in the U.S. must be expected.

Monitoring. If disagreement persists as to what constitutes an appropriate indicator of rangeland condition and trend, it is not surprising that scientists have difficulties agreeing on appropriate monitoring technology. Even in the U.S., which arguably has the best technological means available for this task, rangeland condition is a hotly contested issue. Historically, emphasis in the U.S. was on forage value. The method employed is the Range Condition (RC) model. This model, used in several modifications by U.S. public land administrators, is based on the concept of climax or potential natural community, i.e. employs plant community composition as a benchmark. However, the discussion is ongoing as to whether it is possible to separate ecological condition from suitability for specific uses (Smith, 1979; Floyd and Frost, 1987; Dyksterhuis, 1988). The new State and Transition model, outlined above, does currently not serve as the conceptual basis for monitoring techniques. Thus, there is a noticeable gap between ecological theory and state of monitoring technology. However, it is generally agreed that grazing demand and fire management should be planned and monitored because they constitute the dominant influences on most rangelands. Recently, decision support tools have become available that allow for the balancing of forage supply and demand under explicit consideration of vegetation management objectives (Kothmann and Hinnant, 1997; 1999). Implementation of these tools must be expected to be slow, however, in particular in developing countries where extension services to support producer-based monitoring are largely non-existent.

Global Context

The previous discussion suggests that the development potential of intensive systems and the future production potential of extensive systems may not be commensurate with the supply required to satisfy the expected increases in demand for livestock products. Missing from our analysis as well as from the IFRPI report (Delgado *et al*., 1999) is the consideration of the state of fisheries and aquaculture. According to FAO statistics (FAO, 2000), the number of under exploited or moderately exploited fisheries continues to decline, the number of fully exploited fisheries remains constant, whereas the number of overexploited, depleted or recovering fisheries is increasing. Close to 50% of all fisheries are already fully exploited, and 15 – 20% are overexploited. Jackson *et al*. (2001) recently offered an analysis of the state of fisheries and the critical importance of the assessment of long term data. With currently about 16% of the animal protein intake derived from fish, crustaceans and mollusks, further increases, or perhaps just the stabilization of that proportion will require substantial investments in aquaculture. However, growth in aquaculture output occurred primarily in intensive systems based on formulated feeds. Thus, additional competition for feed grain arising in aquaculture is likely. The realization of the small-holder production potential of aquaculture, primarily in Asia and Africa, is in its early stages. Consequently, increased investments into aquaculture research and development with the aim to reduce dependency on feed crops are critically important, not only for meeting future human demand for animal protein, but also for maintaining current levels of livestock production.

The BSE crisis in Europe has shown convincingly the problems associated with long-range forecasts of supply and demand. It is very important to point out that BSE is the direct result of feeding regimes required to realize the production potential of livestock selected for maximum performance. This has certainly influenced public opinion in Europe and plays a role in the current reformulation of agricultural policies. For example, Germany has recently decided to increase very considerably fiscal engagement in organic and low-input agriculture, at the expense of industrial livestock production.

The considerable risk for human food safety caused by BSE may lead to drastic changes in agricultural policy in Europe in general, and of world trade. It may substantially increase meat exports into the EU, and it may permanently reduce production *and demand* levels in Europe. The occurrence of this catastrophic zoonosis has shown that intensification and attempts at maximization of production may bear important risks. Thus, BSE illustrates the need for great care in the formulation of development policies for the livestock sector.

Conclusions

Livestock production on grazinglands faces major problems. The available resource base is shrinking world-wide. Primary productivity is expected to decline further in many areas. Specialized technology needed to maintain and increase animal production levels without increased input demand is not under development. International institutions seem to have little confidence in the ability of extensive livestock production to contribute substantially to the strong production increases required in the future. There is scientific disagreement about appropriate monitoring goals and technology for the state of the resource.

At the same time, limits to growth of intensive livestock production are becoming clear. When considered in conjunction with the production increase required to satisfy expected future demand for livestock products, it may be concluded that the importance of extensive livestock production systems will increase. Consequently, investment into pertinent technology is justified. Unfortunately, key policy documents (Delgado *et al.*, 1999) do not recognize this need.

Planners will suggest measures to adapt technology appropriate for intensive livestock systems for the development of extensive, grazinglands-based systems. Invariably, such attempts, as in the past, will fail. However, research into the functional basis of adaptation of livestock to harsh grazing environments offers prospects for progress. When combined with research aimed at the better understanding of the nutritional ecology of ruminants, thereby allowing better decision support tools for production systems, it may be possible to maintain and perhaps increase livestock production levels on grazinglands without detrimental effects to the resource base.

Acknowledgements

The senior author wishes to thank the Colombian Corporation for Agricultural Research (CORPOICA, Bogotá, Colombia; Dr Tito Díaz), the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD, Montpellier, France; Dr Gustave Gintzburger) and the Department of Animal and Dairy Sciences, Auburn University, Alabama (Drs Werner Bergen and Russell Muntifering), for invited lectures that were critical to develop this synthesis. This manuscript was invited by the Chilean Society of Animal Production for its 26th annual conference in 2001. We thank Dr. Fernando García (Universidad Católica, Santiago de Chile, SOCHIPA). Helpful review comments by Dr John Rocha, University of Nebraska, are acknowledged.

Literature Cited

Agricultural Research Council (ARC). 1980. The Nutrient Requirements of Ruminant Livestock. CAB, Farnham Royal.

Anon. 2000: Return to an Order of the Honourable the House of Commons dated October 2000 for the Report, evidence and supporting papers of the Inquiry into the emergence and identification of Bovine Spongiform Encephalopathy (BSE) and variant Creutzfeldt-Jakob Disease (vCJD) and the action taken in response to it up to 20 March 1996.

Anon. 2001: http://www.wis.cgiar.org/wisard/shared/asp/projectsummary.asp?Kennummer=4200

Baptist, R. and A.B. Carles. 1989. How can litter size affect wool production with zero genetic and phenotypic correlations? Proceedings of the Small Ruminant Collaborative Research Support Project Workshop Nairobi VII:124-130.

Beever, D.E., M. Gill, J.M. Dawson and P. J. Buttery. 1990. The effect of fishmeal on the digestion of grass silage by growing cattle. Br. J. Nutr. 63:489-502.

Blackburn, H. D. and W. Pittroff. 1999. Biologically based coefficients for partitioning lamb and wool production costs. J. Anim. Sci. 77:1353-1363.

Blümmel, M., H. Steingass and K. Becker. 1997. The relationship between in vitro gas production, in vitro microbial biomass yield and 15N incorporation and its implication for the prediction of voluntary feed intake. Br. J. Nut. 77:911-921.

Brosh, A., Y. Aharoni, A. A. Degen, D. Wright, and B.A. Young. (1998). Estimation of energy expenditure from heart rate measurements in cattle maintained under different conditions. Journal of Animal Science 76: 3054-3064.

Caprio, M., Fabbrini, E., Isidori, A., Versa, A. and A. Fabbri. 2001. Leptin in reproduction. Tr. End. Met. 12 (2):65-72.

De Haan, C., Steinfeld, H., and H. Blackburn. 1997. Livestock and the Environment: Finding a balance. European Commission, Directorate General for Development, Bruxelles.

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui and C. Courbois. 1999. Livestock to 2020: The next food revolution. Food, Agriculture, and the Environment Discussion Paper 28. International Food Policy Research Institute, Washington, D.C.

Dyksterhuis, E. J. 1988. Comments prompted by article on condition classes in August 1987 issue of Rangelands. Rangelands 10(1):67-70.

Falconer, D. S. 1989. Introduction to quantitative genetics. Longman Scientific and Technical, Harlow, Essex.

FAO. 2000. World review of fisheries and aquaculture. Available http://www.fao.org/docrep/003/x8002e/x8002e04.htm. Accessed Jan. 2, 2002.

Fattet, I.,. F.D. Hovell, E.R. Ørskov, D.J. Kyle,. K. Pennie and R.I. Smart. 1984. Undernutrition in sheep. The effect of supplementation with protein on protein accretion. Br. J. Nut. 52:561-574.

Floyd, D. and W. Frost. 1987. Measuring management objectives with condition classes: time for a change. J. Range Manage. 9:65-66.

Folke, C., C.S. Holling, and C. Perrings. 1996. Biological diversity, ecosystems, and the human scale. Ecol. App. 6: 1018-1024.

Friedman, J.M. 1998. Leptin, leptin receptors, and the control of body weight. Nutrition Reviews 56:S38-S46.

Hammond, J. 1947. Animal breeding in relation to nutrition and environmental conditions. Biological Review of the Cambridge Philosophical Society 22:195-213.

Holling, C. S. 1973. Resilience and stability of ecological systems. Ann. Rev. Ecol. Syst. 4:1-23.

Holtzman, N. A. 2001. Putting the search for genes in perspective. Int. J. Health Serv. 31:445-461.

Huntsinger, L. Buttolph, and P. Hopkinson. 1997. Changes in ownership, use, and management of California's hardwood rangelands, 1985-1992. J. Range Manage. 50:423-430.

Illius A. W. and M. S. Allen 1994: Assessing forage quality using integrated models of intake and digestion in ruminants. In: Fahey, G C (Ed): Forage Quality, Evaluation and Utilization. American Society of Agronomy, Inc. Madison, WI, USA.

Jackson, J. B. C, Kirby, M. X., Berger, W.H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J. A., Terence P. Hughes, S. Kidwell, Carina, B. Lange, Hunter S., Lenihan, John M. Pandolfi, Charles H. Peterson, Robert S. Steneck, Mia J. Tegner, Robert R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629-638.

Joandet, G. E. and T. C. Cartwright. 1975. Modeling beef production systems. J. Anim. Sci. 41:1238-1245.

Johnson, H. B. and H. S. Mayeux. 1992. Viewpoint: A view on species additions and deletions and the balance of nature. Journal of Range Management 45:322-333.

Klapp, E. 1971. Wiesen und Weiden. Verlag Paul Parey, Berlin. 620 p.

Kothmann, M. M., and R.T. Hinnant. 1997. Pages 9-10 in The Grazing Manager: A new application of the carrying capacity concept. pp. 26:9-10, in Proceedings Vol. 2, XVIII International Grassland Congress, June 8-19, 1997, Winnipeg, Manitoba & Saskatoon, Saskatchewan, Canada.

Lachica, M., J.F. Aguilera, and C. Prieto. 1997. Energy expenditure related to the act of eating in Granadina goats given diets of different physical form. Brit. J. Nut. 77:417-426.

Lyons, R.K. and J.W. Stuth. 1992. Fecal NIRS equations for predicting diet quality of free-ranging cattle. J. Range Manage. 45:238-244

National Research Council (NRC). 1996. Nutrient Requirements of Beef Cattle. Seventh Rev. ed. National Academy Press, Washington, DC.

Noy-Meir, I. and B. H. Walker. 1986. Stability and resilience in rangelands. In: Joss, P.J., Lynch, P. W. and O. B. Williams (eds): Rangelands: A Resource under Siege. Australian Academy of Science, Canberra. P. 21-25.

Ørskov, E.R. and D. A. Grubb. 1978. Validation of new systems for protein evaluation in ruminants by testing the effect of urea supplementation on intake and digestibility of straw with or without sodium hydroxide treatment. J. agri. Sci., Camb. 91:483-486.

Ørskov, E.R. 1992. Protein Nutrition in Ruminants. Academic Press, London.

Pittroff, W. and M. M. Kothmann (1999): Intake Regulation and Diet Selection in Herbivores. Pages 366-422 in Nutritional Ecology of Herbivores. Proceedings of the V[th] International Symposium on the Nutrition of Herbivores. American Association of Animal Science, Savoy, IL, USA.

Pittroff, W. and M. M. Kothmann (2001a): Quantitative prediction of feed intake in ruminants. 1. Conceptual and mathematical analysis of models for sheep. Livest. Prod. Sci. 71:131-150.

Pittroff, W. and M. M. Kothmann (2001b): Quantitative prediction of feed intake in ruminants. 2. Conceptual and mathematical analysis of models for cattle. Livest. Prod. Sci. 71:151-169.

Pittroff, W. and M. M. Kothmann (2001c): Quantitative prediction of feed intake in ruminants. 3. Comparative example calculations and discussion. Livest. Prod. Sci. 71:171-181.

Postel, S. 1999. Pillars of Sand. Worldwatch Book. Worldwatch Institute, Washington, D.C. 313 p.

Reynolds, C. K., H. F. Tyrrell, and P. J. Reynolds. 1991. Effects of diet forage to energy ratio and intake on energy metabolism in growing beef heifers: whole body energy and nitrogen balance and visceral heat production. J. Nutr. 121:994-1003.

Robinson, P. M. Gill., and J.J. Kennelly. 1997. Influence of time of feeding a protein meal on ruminal fermentation an.d forestomach digestion in dairy cows. J. Dairy Sci. 80:1366-1373.

Rosegrant, M., M. Agcaoili-Sombilla, and N. Perez. 1995. Global food projectsions to 2020: Implications for investment. Food, Agriculture, and the Environment Discussion Paper 5. International Food Policy Research Institute, Washington, D.C.

Samartin, S. and R. K. Chandra. 2001. Obesity, overnutrition and the immune system. Nutrition Research 21:243-262.

Santos Alvarez, J., Goberna, R. and V. Sanchez Margalet. 1999. Human leptin stimulates proliferation and activation of human circulating monocytes. Cel. Immun. 194:6-11.

Shabi, Z., Arieli, A., Bruckental, I., Aharoni, Y., Zamwel, S., Bor, A., and H. Tagari. 1998. Effect of synchronization of the degradation of dietary crude protein and organic matter and feeding frequency on ruminal fermentation and flow digesta in the abomasums of dairy cows. J. Dairy Sci. 81: 1991-2000.

Sinclair, L. A., P. C. Garnsworthy, J.R. Newbold, and P.J. Buttery. 1995. Effects of synchronizing the rate of dietary energy and nitrogen release in diets with a similar carbohydrate composition on rumen fermentation and microbial protein synthesis in sheep. J. Agric. Sci. 124:463-472.

Skarpe, C. 2000. Desertification, no-change or alternative states: Can we trust simple models on livestock impact in dry rangelands? App. Veg. Sci. 3:261-268.

Smith, E. Lamar. 1979. Evaluation of the range condition concept. Rangelands 1:52-54.

UNEP 1992. Status of desertification and implementation of the United Nations Plan of Action to Combat Desertification. UNEP, Nairobi

Vipond, J. E., King, M.E., Ørskov, E.R and G.Z. Wetherill 1989. Effects of fish-meal supplementation on performance of overfat lambs fed on barley straw to reduce carcass fatness. Anim. Prod. 48:131-138.

Weiss. K. M. amd J. D. Terwilliger. 2000. How many diseases does it take to map a gene with SNPs? Nat. Gen. 26:151-157.

Westoby, M., B. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. J. Range Manage. 42:266-274.

Witt, M. W., L. A. Sinclair, R. G. Wilkinson and P. J. Buttery. 1999. The effects of synchronizing the rate of dietary energy and nitrogen supply to the rumen on the production and metabolism of sheep: food characterization and growth and metabolism of ewe lambs given food ad libitum. Anim. Sci. 69:223-235.

Zemmelink, G. and L. 't Mannetje. 2002. Value for animal production (VAP): a new criterio for tropical forage evaluation. Anim. Feed Sci Tech. 96:31-42.