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9. ABSTRACT
The four papers in this volume concern the world's forage potential on lands with widely varying growing conditions. They examine the potential of the world's natural grasslands and cultivated forages and the kinds of strategies needed to exploit these potentials. They cover temperate zone cultivated forages, humid and sub-humid rangelands, tropical zone cultivated forages, and arid and semi-arid rangelands. The arable land of the humid temperate regions of the world must include some forage production as well as grain production if the productivity of the land is to be maintained. Ruminant animals of the humid, temperate region have in the past provided a stable and nutritious food supply by consuming an all-forage diet. In a tropical environment, grain feeding systems of high cost are rarely used in ruminant production. Ruminants are either grazed on land unsuited to cropping, where their comparative conversion of high fiber diets is preeminent, or they are run in conjunction with cropping land, consuming residue which would otherwise be wasted. A vast majority of livestock in the tropics graze native and natural grasslands; relatively few have access to improved pastures. Use of cultivated grass, legume species, and cultivars and the implementation of agronomic practices, along with appropriate animal management and judicious managerial skills, could measurably increase animal production in the tropics and subtropics. The potential for increased ruminant production from arid and semi-arid rangeland is good. Various estimates exist as to the extent to which this can be accomplished. Major changes in range management are likely to occur. Food chains will be shortened, much rangeland will be converted to crop production, animal protein will be produced from those areas unsuitable for crop production, and rangelands will serve as major recreational and waste disposal areas.

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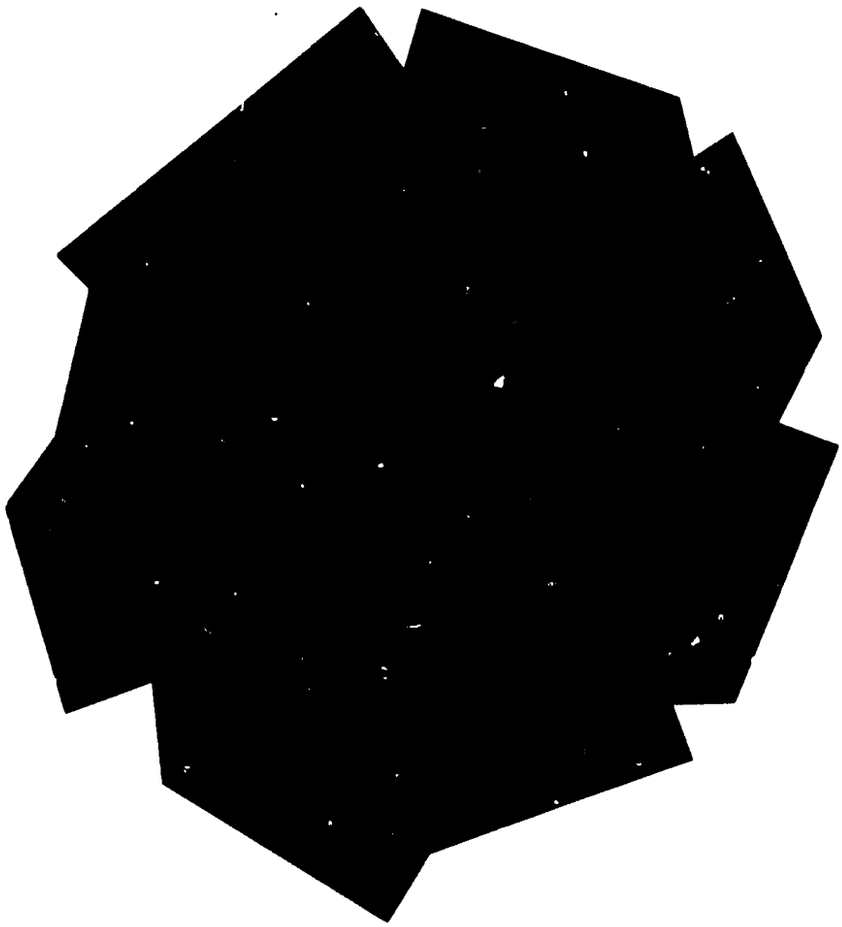

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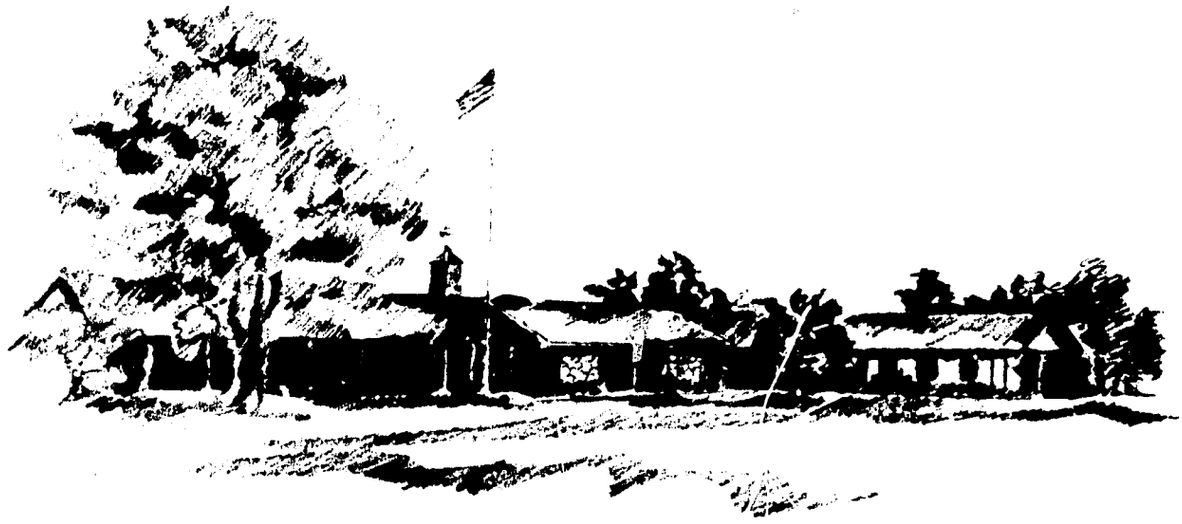

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Winrock Report

POTENTIAL OF THE WORLD'S FORAGES FOR RUMINANT ANIMAL PRODUCTION

- Temperate Zone Cultivated Forages
- Humid and Subhumid Tropical Rangelands
- Tropical Zone Cultivated Forages
- Arid and Semi-Arid Rangelands

Winrock International Livestock Research and Training Center
Petit Jean Mountain, Morrilton, Arkansas 72110
September, 1977

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Bula, Lechtenberg, and Holt

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FOREWORD

For several millenia, man has had a highly favorable relationship with ruminant animals — cattle, sheep, goats, water buffaloes, camels and others. Ruminants contribute to the support of man by supplying not only highly nutritious food — meat, milk and milk products — but also fiber, hides, skins and a host of useful byproducts. In some cultures, man relies heavily on ruminants as a source of draft power, fuel and fertilizer.

Ruminants are particularly well adapted to utilize as their principal source of feed the forages and browse produced on the vast areas of permanent pasture and meadow in the world — most of which are not suitable for crop production — together with forages produced on arable land. Even in countries where ruminants are fed liberal grain supplements to fatten them, forage still contributes about 75 percent of the nutrients the animals consume. In areas of the world where grain feeding is not common, ruminants obtain about 95 percent of their nutrient requirements from forage.

During the remainder of this century, ruminant livestock are expected to become increasingly dependent on forages. The reason for this, according to most authorities, is that a rapidly expanding human population will force man to compete more actively with livestock for edible grains, thus resulting in animals being fed less grain and more forages.

In the developing countries of the world, production per animal unit — whether it be food or fiber — is much lower than it is in the developed world, simply because an animal in a developing country uses a higher proportion of its feed for body maintenance. Thus, less of its feed intake is converted to products useful to man. This unfortunate situation can result from an inadequate supply of forage or other feeds, low nutritive forage quality during at least part of the year, or the sporadic seasonal availability of forage.

Inadequate or low quality feed supplies can have a number of significant impacts on animal productivity: (a) reduced fertility levels resulting in low calving rates and, frequently, alternate-year breeding instead of annual breeding; (b) slow growth rates because of cyclical patterns of weight gain and loss which in turn means that it may take an animal 5 to 7 years to reach market weight; and (c) higher susceptibility of the animals to the debilitating effects of diseases and insects.

All of this adds up to the fact that the critical constraint in animal production is the intake of digestible nutrients, which in turn is influenced principally by feed availability and digestibility. Other factors such as disease, low genetic potential of animals and temperature stresses will constraint productivity. But the primary constraint in much of the world is the feed supply.

Because forages are so important in ruminant production, and because human desires and needs for ruminant products are so strong, those who plan agricultural production strategies of the future need to seriously consider the potential for increasing the forage energy supply to ruminants. The role of forages and ruminants is often overlooked. It should not be.

The four papers in this volume carry especial significance because they dwell exclusively on the subject of the world's forage potential on lands with widely varying growing conditions.

They delineate both the potential of the world's natural grasslands and cultivated forages and the kinds of strategies needed to exploit these potentials. The authors are highly knowledgeable authorities on their subjects. Their respective chapters represent viewpoints developed from consideration of both research results and practical experience. These viewpoint papers were commissioned by Winrock International as part of its research project, "The Role of Ruminants in Support of Man."

The views presented in this volume seem worthy of earnest consideration as the world strives to better feed its rapidly increasing population from its often poorly used supply of renewable resources.

Harlow J. Hodgson*

**Dr. Hodgson, a noted authority on forage-ruminant production systems, has served as one of the principal senior consultants to the Winrock International research program. He is currently Assistant to the Director, Agricultural Experiment Station, University of Wisconsin, Madison, Wisconsin 53706.*

POTENTIAL OF TEMPERATE ZONE CULTIVATED FORAGES

For Ruminant Animal Production

R.J. BULA[1], V.L. LECHTENBERG[2], and D.A. HOLT[2]

Between the winterless and summerless areas of the world are broad intervening regions where seasonal temperatures vary markedly. These intermediate or middle latitudes of the world are generally designated as the temperate regions. Another climate element, precipitation, further differentiates these broad regions.

The highest level of technological development has occurred within the temperate regions, and this development includes the art and science of food production. Over the years, the temperate regions, which have adequate rainfall during the growing season, have been the major sources of the world's food supply. North America, for example, produces about 20 percent of the world's grain but accounts for 50 to 60 percent of world grain exports.

As the agricultural societies of these climatic regions evolved, a forage-livestock enterprise developed that was complementary to the grain enterprise. Within the last 50 years, however, our knowledge of agricultural science and fertilizer technology was developed to the point where many of the complementary aspects of a grain-forage-livestock enterprise were ignored. Grain crops were produced as monocultures without forage crops rotations. This resulted in enormous supplies of feed grains and relatively low grain prices. Consequently animal products could be produced more efficiently from high-energy grains than from forages.

In the early 1970's, a ballooning worldwide demand for food, resulting from a number of social, economic, and climatic developments, resulted in high worldwide price levels for feed grains. This worldwide demand for food is likely to increase in the future, and projected food needs have led to the suggestion that we can no longer afford the luxury of feeding grain to livestock (*1*). If such a suggestion were followed, the arable land of the humid temperate regions of the world would have to be entirely allotted to grain production for human consumption.

What is ignored is that there are areas of arable land in these regions that must be used for forage production rather than grain production if the productivity of the land is to be maintained. Furthermore, ruminant animals of the humid, temperate region have in the past provided a stable and nutritious food supply by consuming an all-forage diet.

The humid, temperate regions of the world have been and can continue to be a major source of meat and milk as well as grains. As demand grows, the potential for even higher outputs can quite likely be achieved.

PHYSICAL CHARACTERISTICS OF THE HUMID, TEMPERATE REGIONS

Most geographers define the temperate zone to be within the latitudes of 30 to 60°. In the northern hemisphere, there are areas as far north as 65° in Finland, Alaska, and the USSR where livestock agriculture is practiced. This does not include reindeer herding that can be a food source and is practiced at even higher latitudes than 65°. To further define the climate, the humid, temperate regions included in these discussions have an annual rainfall of 50 to 200 cm.

Classically, the climate groups of these regions are defined as the humid mesothermal and microthermal groups (*2*). Included in these climatic groups are the humid, continental climates (both cool and warm summer); the humid, subtropical; and the marine, cool summer climates. These climates are characterized by rapid and marked non-periodic weather

[1]Area Director, Agricultural Research Service, U.S. Dept. of Agriculture, Lafayette, IN 47907.
[2]Associate Professors of Agronomy, Dept. of Agronomy, Purdue University, Lafayette, IN 47907.

changes, superimposed over the seasonal changes.

North of the humid, continental, cool summer climatic region is the subarctic or taiga climatic region. In spite of the fact that the subarctic is one of the most extensive of the earth's geographic realms, it is also one of the least productive. Man has struggled to push commercial agriculture poleward, but the process has been extremely slow because of the harsh climatic conditions. In our opinion, agricultural development in the taiga region will be negligible during the next 25 years and thus, this region is not included in our projections.

The humid, temperate regions defined as to political entities are listed in Table 1. There are other areas in the world that have humid, temperate climates (Chile, Argentina, Australia, and parts of North and South Dakota, Nebraska, Kansas, Oklahoma, Texas, Oregon, and Washington in the U.S.). However, these areas are not included because they are relatively minor compared to the areas defined in Table 1 and their agricultural production is difficult to separate from that of the semi-arid regions within these countries or states.

The areas of arable and permanent meadow or grazing lands within the humid, temperate climates are listed in Table 2. Estimates of grazing land area refer to permanent meadows and pasture. The estimates of both arable and grazing land areas may contain some error because of differences in the definition of these two land classes among different countries.

The humid, temperate regions include about 29 percent of the world's total arable land area and 10 percent of the permanent grazing land area. Allocation of arable land to the production of various crop plants has been based largely on economic considerations. However, permanent grazing lands have few, if any, alternate uses other than to produce feed for ruminant livestock.

There is a surprisingly large land area within the humid, temperate region that is maintained as permanent grassland. This land area does not include the semi-arid steppe or range lands. For example, Western Europe has an estimated 60 million hectares of permanent grazing lands compared with 74 million hectares of arable land. In New Zealand there are over 12.5 million hectares of grazing land area and only 0.8

The humid temperate regions produce more than 60 percent of the world's beef and veal production. ***Photo by Ohio Agr. Research & Dev. Center.***

Table 1. Countries and political entities included in the humid, temperate climates of the world

Region	Political entities
North America	Canada — Provinces of Prince Edward Island, Nova Scotia, New Brunswick, Quebec, Ontario, British Columbia.
	United States — States of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Delaware, Maryland, West Virginia, Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Arkansas, Louisiana, Mississippi, Kentucky, Tennessee, Alabama, Florida, Georgia, South Carolina, North Carolina, Virginia, and Alaska.
Western Europe	Austria, Belgium, Denmark, Finland, France, West Germany, Iceland, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom.
Eastern Europe	Albania, Bulgaria, Czechoslovakia, East Germany, Greece, Hungary, Poland, Romania, Yugoslavia.
Union of Soviet Socialist Republic	Area west of the Ural Mountains and north of the Caspian Sea, a small area in eastern Asia near Vladivostok.
Asia	China — North of the 30th parallel and east of the Plateau of Tibet and The Great Khingan Mountains, commonly called the North China and Manchurian Plains.
	Japan — North of Tokyo on Honshu Island and Hokkaido Island.
	North Korea
	South Korea
New Zealand	All of the country

Table 2. Arable and grazing land area in the various geographic regions of the humid, temperate climates in the world

	Arable land	Grazing and meadow
	Thousand hectares	
North America	104,145	24,052
U.S.	97,500	21,200
Canada	6,645	2,852
Western Europe	74,213	60,781
Eastern Europe	54,221	26,906
USSR	118,401	100,514
Asia	70,296	57,069
New Zealand	820	12,680
Subtotal	422,096	292,002
World total	1,472,929	2,992,308

Sources: Items 3, 4, 5, 6 in References and Notes

million hectares of arable land, an obvious reason why New Zealand's agriculture is based on ruminant animals.

The great soil groups of the humid, temperate climate regions range from podzols to gray-brown forest soils, to red-yellow podzolic latosols, to the degraded chernozems or prairie soils. The rolling topography was formed largely by glacial movement and subsequent deposition of a mantle of fine particles. In spite of the variability, these soil regions are the most habitable of the major landforms and have a large food-producing capacity. It seems logical, therefore, that these regions also contain the principal centers of world population.

Crop productivity of these soils can be maintained at high levels with appropriate soil management practices. Conversely, the erodibility of unprotected, row-cropped fields can be 10 to 50 times as great as that of natural prairies or with vegetation of presettlement days. The high price of grains has resulted in the use of many areas for row-crop culture that would best be used for forage crop production. Such practices have accentuated serious erosion problems that are environmentally acceptable.

CURRENT FORAGE AND PASTURE PRODUCTION

The proportion of arable land producing forages — either as hay, silage, or root crops — ranges from 15 to over 40 percent, (Table 3). Countries that have areas well suited for production of grain crops such as maize, wheat, and soybeans (U.S., France, Italy) have small areas of arable land in forage production. On the other hand, the high percentages are associated with countries in the more northern regions of the humid, temperate climates where grain crops are not particularly well adapted or where harvesting is a problem (Canada, U.K., Denmark).

A large number of grass and legume species are used for cultivated forage production in the humid, temperate regions. A list of the most important species appears in Table 4. The species shown are not adapted to all regions of the humid, temperate climates so that the relative importance of any one species varies with the climate.

In addition to the forage production from the areas where grasses and legumes are cultivated, residues from grain crops and industrial by-products of grains produced in the temperate regions comprise a sizeable feed source for ruminants. Wedin et al. (*10*) estimate that residues remaining in the field from maize and sorghum grain production could maintain 20 million beef cows annually. Presently, only a part of these residues is effectively used, mostly because their nutritive value limits their use to animals such as beef cows that are fed essentially maintenance rations.

Table 3. Arable land area planted to forages and forage productivity of the humid, temperate regions of the U.S., Canada, and the 9-member countries of the European Common Market

	Canada	Europe	U.S.
Hay, (Thous. ha)	2,651	12,024	12,722
Hay production, (Thous. MT)	13,561	96,192	78,600
Corn and Sorghum Silage, (Thous. ha)	356	—	2,297
Corn and Sorghum silage production, (Thous. MT)	10,078	—	80,612
Field roots, (Thous. ha)	4	1,256	—
Field roots production, (Thous. MT)	101	82,016	—

[1] Includes the following countries: France, Italy, Netherlands, Belgium, Denmark, Luxemburg, Ireland, West Germany, and United Kingdom.

Sources: Items 7, 8, 9 in References and Notes

MT = metric tons

ha = hectare

Table 4. Listing of the major grass and legume species used for cultivated forage production in the humid, temperate regions of the world

Common name	Scientific name
Perennial legumes (cool climates)	
Alfalfa	Medicago sativa L., and falcata L.
Red clover	Trifolium pratense L.
Alsike clover	Trifolium hybridum L.
White and Ladino clover	Trifolium repens L.
Birdsfoot trefoil	Lotus corniculatus L.
Crown vetch	Coronilla varia L.
Sainfoin	Onobrychis spp
Perennial legumes (warm climates)	
Alfalfa	
Sericea lespedeza	Lespedeza cuneata (Dumont) G. Don, and other closely related spp.
Big trefoil	Lotus pedunculatus Cav.
Narrowleaf trefoil	Lotus tenuis Waldst. and Kit.
Biennial legumes	
Sweet clover	Melilotus officinalis L. and Melilotus alba, Desr.
Annual legumes (cool climates)	
Sweet clover	Melilotus alba, Desr.
Vetches	Vicia spp.
Field peas	Pisum sativum subsp. arvense L.
Lupines	Lupines spp.
Annual legumes (warm climates)	
Spotted burclover	Medicago arabica Huds.
Striate lespedeza	Lespedeza striata (Thumb) H & A
Korean lespedeza	Lespedeza stipulacea Maxim
Crimson clover	Trifolium incarnatum L.
Arrowleaf clover	Trifolium vesiculosum Savi
Lupines	Lupines spp.
Cowpea	Vigna sinensis (L.) Savi ex Hassk.
Root crops	
Mangels, swedes, turnips and fodder carrots	Beta, Brassica, and Daucus spp.
Perennial grasses (cool climates)	
Meadow foxtail	Alopecurus pratensis L.
Tall oatgrass	Arrhenatherum elatius (L.) Presl.
Bluegrass	Poa pratensis L.
Redtop	Agrostis alba L. and other spp.
Smooth bromegrass	Bromus inermis Leyss.
Reed canary grass	Phalaris arundinacea L.
Timothy	Phleum pratense L.
Orchardgrass	Dactylis glomerata L.
Tall fescue	Festuca arundinacea Schreb.
Meadow fescue	Festuca elatior L.
Fine-leaved fescues	Festuca rubra L. and other similar spp.

Common name	Scientific name
Perennial rygrass	Lolium perenne L.
Quackgrass	Agropyron repens L.
Perennial grasses (warm climates)	
Bermudagrass	Cynodon dactylon (L.) Pers.
Bahiagrass	Paspalum notatum Flugge
Carpet grass	Axonopus affinis chase
Johnsongrass	Sorghum halapense L.
Annual grasses (cool climates)	
Italian rygrass	Lolium multiflorum Lam.
Millets	Setaria spp.
Sudangrass	Sorghum bicolor (L.) Moench.
Oats	Avena spp.
Rye	Secale spp.
Barley	Hordeum spp.
Maize	Zea mays L.
Annual grasses (warm climates)	
Sorghum and sudangrass	Sorghum bicolor (L.) Moench.
Millets	Setaria spp.
Pearl millet	Pennisetum typhoides (Burm.) Staph. & C. E. Hubb.
Maize	Zea mays L.
Italian ryegrass	Lolium multiflorum Lam.

CURRENT RUMINANT ANIMAL PRODUCTION

The humid, temperate regions of the world maintain approximately 30 percent of the world's ruminant animals. Statistics are not readily available for numbers of animals or animal products in the various climatic regions of the USSR and China. Thus, the estimated numbers of forage consuming animals, particularly sheep and goats, in the humid temperate regions of these two countries may not be as high as given in Table 5.

Even though the number of sheep and goats is estimated to be slightly higher than the number of cattle (beef and dairy) and buffalo, this latter group of ruminants represents the major consumer of forages. This is further illustrated in Table 6 which shows the amount of animal products produced in the various geographic regions of the humid temperate climates. Most of the animal products are derived from beef and veal or from milk.

The humid, temperate regions produce over 70 percent of the world's whole milk and more than 60 percent of the beef and veal. Eastern and Western Europe alone account for about 38 percent of the world's whole milk production. Recognition that approximately 75 percent ofthe feed consumed by beef cattle and 60 percent of the feed consumed by dairy animals is forage emphasizes the contribution that forages make to our current food supply. Expressed in terms of human food of animal origin, forages exceed the value of any other crop in the humid, temperate regions of the world. In the U.S., beef and dairy products supply about one-fourth of the total energy intake and two-fifths of the total protein consumed by humans (*12*).

PRODUCTION POTENTIALS

Plant Productivity

Agriculture is presently faced with three clearly discernible trends that are quite likely to continue until at least the year 2000: (1) rising prices of grain used for animal feed, (2) increased demand for animal products in human diets, and (3) declining supplies of fossil fuels. These trends most certainly will

Table 5. Number of domestic forage consuming animals in the various geographic regions of the humid, temperate zone in the world

	Cattle & buffalo	Sheep & goats
	Thousands	
North America	65,600	3,700
U.S.	59,600	3,300
Canada	6,000	400
Western Europe	87,500	82,000
Eastern Europe	48,400	54,300
USSR	106,700[1]	148,500[1]
Asia	99,500[1]	132,300[1]
New Zealand	9,400	55,900
Subtotal	417,100	476,700
World total	1,309,178	1,430,584

[1] Includes animals in all climatic regions in these countries.
Sources: Items 5, 7, 9 in References and Notes

Table 6. Ruminant animal products produced in the various geographic regions of the humid temperate zone in the world

	Beef & veal	Lamp, mutton & goat meat	Whole milk
		Thousand MT	
North America	5,119	13	44,800
U.S.	4,200	5	38,100
Canada	919[1]	8[1]	6,700
Western Europe	6,700	762	103,000
Eastern Europe	3,200	328	58,500
USSR	6,400[1]	1,050[1]	92,265[1]
Asia	2,300[1]	597[1]	10,100[1]
New Zealand	401	493	5,600
Subtotal	24,120	3,243	314,265
World total	42,045	6,860	424,295

[1] Includes animal products from all climatic regions in these countries.
Sources: Items 5, 9, 11 in References and Notes

stimulate new research and technology application in all areas of forage crop production.

The increased world demand for grain and favorable grain prices have encouraged the expansion of grain production into areas that have previously been in forages. Consequently, the percentage of arable land devoted to forage production in the humid, temperate regions of the world has been decreasing in recent years. However, this trend is not likely to continue because some of these areas have particularly serious erosion problems and should not be in row-crop production unless very intensive erosion control measures, such as contouring and terracing, are employed.

Very far-reaching legislation has been proposed to reduce the quantities of plant nutrients and soil in the surface drainage and ground water originating on farmland. To meet these restrictions, many areas now in

row-crop production may have to be returned to either rotation or permanent hay and pasture lands. Pollution control legislation is almost certain to encourage an increase in production of forage crops during the next 25 years. The development of new and more profitable forage production systems competitive with grain crop production will reduce the economic impact of the restrictive land use legislation. Thus, the amount of arable land in the humid, temperate region of the world devoted to forage crops should remain at the present level of 55 to 60 million hectares for the forseeable future.

Productivity of intensively managed, cultivated forages grown on arable land in the temperate, humid regions of the world has been estimated by Greenhalgh (*13*) to be around 12.5 MT/ha per year of milk yield or 1.75 MT/ha per year of liveweight beef gain. Holmes (*14*), making similar assumptions, concluded that high levels of management should lead to the production of 11.7 MT of forage dry matter per hectare per year. In a 3-year study under essentially commercial farming conditions, Rhykerd et al. (*15*) obtained over 15 MT of forage dry matter per hectare per year by intensively managing an alfalfa-grass sward.

Such estimates and experimental observations indicate that the forage productivity of arable land in the humid, temperate regions of the world could easily be doubled by using an adequate level of fertilization and harvesting the forage when the grasses or legumes begin flowering. The current level of 6 to 8 MT per hectare per year as indicated in Table 3 could be increased to 15 MT per hectare. These improved management practices would also increase forage digestibility and increase the efficiency of energy utilization of the forage by the ruminants.

Using the estimate of 12.5 MT per hectare of milk yield, the potential annual milk yield from arable land in the humid, temperate regions of the U.S. now producing hay could be over 160 million MT compared to the 38 million reported for 1974 (Table 6). Likewise, using the estimate of 1.75 MT per hectare of liveweight beef gain, the potential red meat production of the 12.7 million hectares of hay in the humid temperate region of the U.S. could be 22 million MT. Although these examples illustrate U.S. conditions, similar potentials exist in the other humid temperate regions of the world.

It should also be pointed out that the 38 million MT of whole milk and 8.6 million MT of beef, veal, sheep and goat meat products given in Table 6 represent animal products from both forage and grain supplement fed the animals. The potential of 160 million MT of whole milk and 22 million MT of liveweight beef gain are derived from the 12.7 million hectares of arable land devoted to hay production and does not represent any contribution from grain supplement fed to the animals.

Table 2 shows that almost 300 million hectares of land area in the humid, temperate regions of the world are maintained as grazing lands or permanent meadows. This land is generally too rough, sloping, or rocky for efficient use of machines or grain production. This land must and should, for the most part, be pastured. In general, this land is very poorly managed, being either under-utilized or overstocked. As is the case with forage productivity of the arable land, the production from the permanently grazed areas could be increased substantially over the next 25 years by applying the following improved forage practices; proper fertilization, renovation through establishment of legumes and desirable grasses, and more efficient grazing practices.

Numerous studies in all regions of the humid, temperate climates have shown that productivity of natural grasslands can be substantially increased if reasonable fertilizer applications are used. For example, increases in dry matter yields from 2.5 MT/ha to over 10 MT/ha were reported by Scholl and Llambias (*16*) when *Poa pratensis L.* pastures in southern Wisconsin were fertilized with 120, 40, and 80 kg/ha of nitrogen, phosphorus, and potassium, respectively. In Czechoslovakia, dry matter yields of natural grasslands were increased from 1.5 MT/ha to near 10 MT/ha by similar fertilizer treatments (*17*).

Productivity of *Poa pratensis* renovated by including a legume, in this case *Lotus corniculatus*, was increased from 100 kg/ha of liveweight beef gain per year to almost 300 kg/ha (*18*). These increases were obtained on soils of the corn belt regions in the U.S. with relatively low row-crop productivity potentials. Use of efficient grazing practices such as rotational or seasonal grazing resulted in even

higher animal productivity of these permanent pastures.

Thus, if only one-half of the 300 million hectares of permanent grazing lands or meadows in the humid temperate regions of the world were treated with moderate levels of phosphorous and potassium, 40 and 80 kg/ha, respectively, and renovated to include a legume, the red meat production from these areas would be around 45 million MT per year. When this is added to the 100 million MT potential from the 60 million hectares of arable land producing cultivated forages, the enormous food production potential of forages of the humid, temperate regions of the world is vividly portrayed.

Silage made from corn or sorghum is also used as a source of forage for cattle and sheep. The prospect for continued high prices of grains will discourage any increase in usage of corn for silage rather than grain. Thus, any additional contribution of silage to animal productivity of the humid, temperate regions will result from increases in yields of digestible energy per unit of land area. Such increase will be made possible by the continued development of higher yielding varieties and by incorporating low lignin or other modified plant characteristics that will increase the percentage of digestible energy of the plant material. As much as a 25 percent increase in yield of digestible energy per unit of land area is within the realm of reality during the next 25 years.

The chemical composition of forage crops varies widely depending on the plant species, the environmental conditions under which they are grown, and the cultural and management practices that are followed. Major chemical constituents of forages consist of nonstructural carbohydrates; such as sugars and starch, protein, minerals, and structural carbohydrates or fiber. Since forage crops are primarily a source of energy for ruminant animals, the relative amounts and the digestibility of these various constituents are very important considerations in the conversion of forage production into animal products. (For the purpose of this discussion, forage digestibility percentage is equated to percentage of digestible energy.)

The concentration of nonstructural carbohydrates in a forage may range from less than 5 percent to greater than 30 percent of the plant dry weight. Protein percentage may range from 2 to 25 percent. Digestibility of the nonstructural carbohydrates and protein is nearly 100 percent. These constituents can be digested and metabolized by monogastric animals as well as by ruminant animals. Because these constituents are nearly 100 percent digestible, forages that contain relatively large amounts of them are generally high quality feeds.

Forages also contain from 40 to 85 percent fiber. It is this high fiber content of forage crops that restricts their use as feeds to ruminant animals. Rumen bacteria are able to break down and digest the cellulose and hemicellulose in plant fiber and convert them to metabolic products that these animals can then use. They are unable to break down lignin, the other constituent of fiber. Consequently, the digestibility of plant fiber is less than 100 percent. It may range from as low as 20 percent to as high as 80 percent. Because of this and the fact that fiber constitutes a large part of the plant tissue, the total digestible energy concentration of a forage may be as low as 35 percent or as high as 80 percent. Green immature pastures may be 70-80 percent digestible energy while high quality, early cut hay may be 65 percent digestible energy. Late-cut, mature hay may be as low as 40 percent and often averages only 50 percent digestible energy. Crop residues are nearly always less than 50 percent and may be as low as 30 percent digestible energy.

The large variation in the digestible energy percentage of various forages is due mainly to the amount of lignin present. Lignin is a constituent of plant fiber that is not digested by rumen microorganisms. In addition, lignin binds with cellulose and hemicellulose and greatly reduces the digestibility of these plant constituents. A unit increase in lignin will commonly result in a three to four unit decrease in the digestible energy percentage of a forage. If lignification did not occur, or if it could be prevented, the digestible energy percentage of most forages would approach that of feed grains.

The amount of lignification and the extent to which it limits the digestible energy percentage of a forage primarily depends on the maturity stage of plants. Lignin content increases and digestible energy decreases rapidly as the plant matures. Figure 1-1 shows changes in lignin and digestible energy percentages that occur as a cool season grass matures *(19, 20)*. Similar maturity changes also occur with other

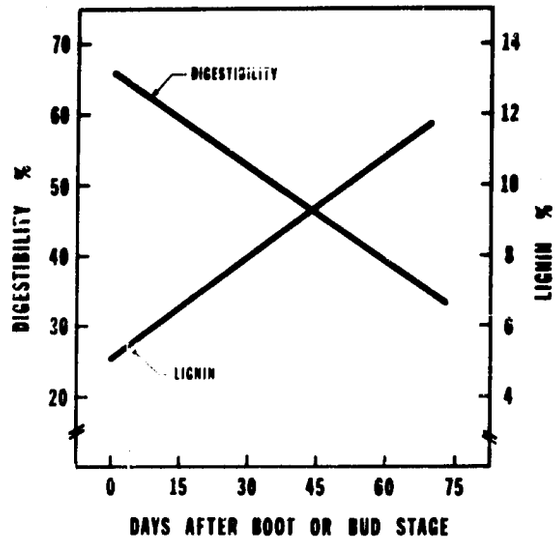

Figure 1-1. — Changes in digestibility and lignin percentage with advancing maturity of harvested forage.

grasses and legumes *(21, 22)*. The digestible energy percentage of cool season grasses and legumes commonly decreases from .3 to .5 percentage unit each day after boot stage in grasses, or bud stage in legumes.

Recognizing the changes in composition and digestible energy percentage as a result of maturity is essential for efficient animal utilization of forage crops. The digestible energy of the feed available for grazing or of that harvested greatly depends on the way crop production and utilization are managed. This is generally not true with grain production, where poor management often results in low yield but the quality of the product is not greatly affected. In forage production, however, poor management not only results in low yield but also in low quality feed. The efficiency with which ruminant animals convert forages to meat and milk can be increased greatly with good forage production and harvesting practices.

Conversion of Forage into Animal Products

Monogastric animals such as man cannot use forages as a source of food. These plant materials must be converted into an animal product to become a food source for man. Much concern has been expressed about the efficiency of this conversion from plant to animal product. Likewise, much remains to be learned about improving this conversion. There is little disagreement, however, about the potential for improvement in animal productivity, if a better understanding of the plant-animal complex is developed.

Forages are used by animals primarily as a source of energy. Of the total energy available in forage, only the digestible energy is usable. Some of this digestible energy is lost as gas during digestion. Some is also lost in urine production. Additional energy is lost as heat during digestion. The energy that remains is the net energy of the forage that is available to meet the animal's maintenance and production needs. The net energy content of a forage depends on its concentration of digestible energy; the efficiency with which this net energy is utilized by the animal depends on whether the animal is using the energy for maintenance, milk production, or weight gain. From 50 to 100 percent of the animal's energy consumption may be needed simply to meet maintenance needs; the amount depends on the forage quality.

Ruminant animals are able to use the energy in feeds much more efficiently for maintenance or milk production than for body weight gain. In addition, the net energy content of a forage when used for maintenance or lactation is influenced less by concentration of digestible energy of the forage than if the energy is used for weight gain. Figure 1-2 shows the effect of forage digestible energy percentage on efficiency of energy utilization for maintenance, milk production, and weight gain relative to that of corn grain *(23, 24, 25)*. At 70 percent digestible energy, forages are 65 to 75 percent as efficient as grain for meeting maintenance and production needs. On the other hand, at 50 percent digestible energy, forages are less than 20 percent as efficient as grain for the production of weight gain — but nearly 50 percent as effective as grain in providing energy for maintenance or milk production.

Figure 1-2 suggests that forages low in digestible energy are very ineffective in providing energy for weight gain. A wise forage utilization program should include feeding these forages to breeding stock or other animals where little or no weight gain is desired. Forages high in digestible energy should be reserved for growing or lactating animals where weight gain or milk production is necessary.

Animal productivity depends not only on

the digestible energy percentage of the feed consumed but also on the amount of feed consumed each day. Daily feed consumption of most forages increases as the digestible energy concentration increases — up to approximately 65 percent digestible energy. Because of the increase in daily feed consumption associated

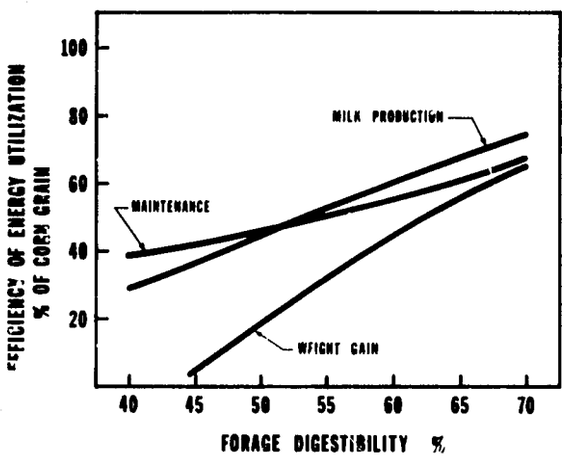

Figure 1-2. — Relationship of forage digestibility on the efficiency of energy utilization from the forage by ruminants, compared to corn.

with an increase in percent digestible energy, the daily consumption of digestible energy increases greatly with only a small or modest increase in forage digestibility (*26, 27, 28*). Figures 1-3 and 1-4 show the effect of forage digestibility on the digestible energy consumed by a 300 kg growing steer and a 500 kg lactating cow, assuming that only forage is fed. The expected levels of production are also indicated. It is apparent from Figures 3 and 4 that weight gain is not possible if the forage digestible energy is less than approximately 50 percent and milk production is possible only at the expense of loss in body weight. Animals will consume only enough digestible energy to meet their maintenance needs at that point. Feeds with greater than 50 percent digestible energy can result in milk production or weight gain. Forages with low digestible energy concentration are often supplemented with grain in order to obtain acceptable animal productivity.

Figures 1-3 and 1-4 demonstrate that tremendous increases in animal production are possible with only a modest increase in digestible energy. If digestible energy is increased from 55 to 60 percent, weight gain with a 300 kg animal can increase three-fold — from .14 to .42 kg per day. An increase to 65 percent digestible energy results in a daily gain of .87 kg. An increase from 55 to 65 percent in the digestible energy of forages fed to lactating animals could result in an increase in milk production from 4.5 to 19.0 kg per day.

In some parts of the humid temperate regions of the world, the only forage fed to ruminant animals is grain crop residue. Most of this is corn or sorghum stover. This material is generally not more than approximately 50 percent digestible energy, resulting in only animal maintenance or perhaps a very low level of productivity. In other areas where grass and legume forages are harvested for livestock feed, harvesting is often done at a late maturity stage

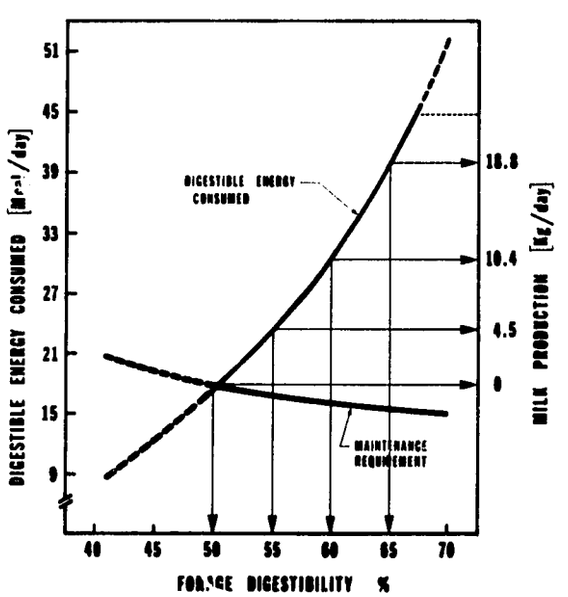

Figure 1-3. — Effect of forage digestibility on digestible energy consumption and weight gain of a 300 kg growing animal.

(Fig. 1-1), and thus the material is too low in digestible energy to support high production levels.

The potential increase in animal productivity is amazingly great if the digestible energy of forage feeds such as late harvested hay or crop residues could be increased from 50 to

60 percent. For example: if a 200 kg growing animal is being fed a mixed ration of 50 percent digestible energy forage and corn grain (approximately 70/30 by weight) the animal will gain nearly 0.45 kg/day. Approximately 220 days will be required to gain 100 kg. In this situation, very little flexibility is available to the producer. Animal production can be increased only by increasing the proportion of grain in the ration or the length of time the animal is fed. On the other hand, if the forage is 60 percent digestible energy, a number of alternatives exist. The forage and grain can be fed in the same proportion as above, but at a daily consumption rate needed to produce .45 kg/day. Less feed/head will be needed each day and 20 percent more animals can be fed on the same tonnage. Alternatively, the same ration could be fed at *ad libitum* consumption. In this case, the animals would consume more feed per day than in the previous situations, but because a smaller proportion of their daily intake would be needed for maintenance, gain would increase to about 0.90 kg/day. The same total gain could be achieved in only 110 days. As a result, 70 percent more animals could be fed on the same amount of grain and forage.

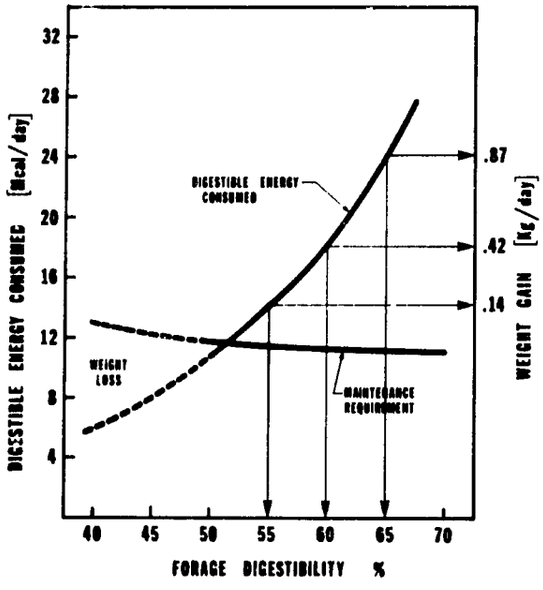

Figure 1-4.— Effect of forage digestibility on digestible energy consumption and milk production by a 500 kg cow.

A third alternative use of the 60 percent digestible energy forage might be to feed only forage and omit grain from the ration. In this case animal gains equal to those in the original situation can be obtained and approximately 400 kg grain saved per head. However, since the animals will consume more forage each day, a 50 percent increase in the amount of forage will be necessary to feed the same number of animals. In this case, high digestible energy forage has been substituted for grain. These examples point out the potential impact that an increase in forage digestible energy can have on animal production.

ACHIEVING THE POTENTIAL

Fertilization

Proper fertilization of forages is essential if they are to reach their production and quality potential. However, the production of some commercial fertilizers requires considerable inputs of fossil energy, supplies of which are finite. This is particularly true of nitrogen, in which case fossil energy is expended to fix atmospheric nitrogen in suitable forms for field use of fertilizer nitrogen. This cost can be avoided by using legumes, which fix their own nitrogen by using solar energy. This unique ability of legumes, some non-legumes, and non-symbiotic nitrogen-fixing organisms to fix nitrogen should be fully exploited to enhance forage crop yields and quality.

Legumes should be used in establishing new forage crop seedings and in renovating old forage crop stands. Besides providing nitrogen for satisfactory production of the legume and any non-legume crops in the forage mixture, the presence of the legume increases the quality of the final product, whether it is pasturage, hay or silage. Interseeding red clover in tall fescue pastures can increase calf weight gains nearly 40 percent (*29*). This results in an increase of approximately 55 kg per calf in liveweight at weaning time. Such increases in animal productivity could be obtained on all of the permanent grazing or arable land used for beef cow-calf production. It is estimated that at least 100 million hectares of the humid, temperate regions of the world are used for beef cow-calf production and are stocked at a rate of 2.0 cow-calf units per hectare. Thus, this

practice alone could increase liveweight meat production by some 11 million MT.

Intensive research efforts are now devoted to identifying species, varieties, and individual plants of grasses which are capable of fixing nitrogen in a symbiotic relationship with certain microorganisms. If this capacity could be discovered in or incorporated into one or more of the perennial, cool season grass species, tremendous benefits would accrue to forage producers. Perennial grasses are generally more persistent than legumes. They are easier to establish in some difficult soil situations, being more tolerant of acid soils and extremely dry or wet conditions. By virtue of their fibrous root system, they are somewhat more desirable than legumes from a soil conservation standpoint. If, in addition to these advantages, grass could fix a significant amount of the nitrogen they require to produce optimum yields, the need to renovate frequently and introduce legumes into perennial pastures would be reduced. A similar advantage would be gained by discovery or selection of active non-symbiotic nitrogen-fixing microorganisms, which, when introduced into a soil, would fix enough nitrogen to supply some of the N required for optimum growth of forage species.

Phosphorus, while essential for plant growth, occurs in lower concentrations in the vegetative part of plants than nitrogen or potassium. Thus the quantity of phosphorus required to promote optimum forage production is smaller than the requirements of nitrogen and potassium. Nevertheless, fossil energy is required to mine, process, and distribute phosphorus fertilizers. Also, there are finite limits to the quantity of phosphorus-bearing minerals which can be used for or readily converted to fertilizer, although the reserves are probably adequate for 2 or 3 centuries (*30*).

An effective program of manure recycling could drastically reduce the need for mineral phosphate fertilizer. Phosphorus is not lost from manure even when severe denitrification has occurred. Rotational grazing and well-planned spreading of manure are effective methods of assuring that phosphorus is returned to the fields from whence it came. Often, hay and silage crops are removed from the field where grown and fed to animals in confinement. Manure is then frequently distributed on crop fields. This results in a net loss of fertilizer nutrients from forage production fields. On the other hand, some forage-animal utilization systems, such as grain feeding of animals on pasture, result in the net addition of nutrients to the pasture since most of the nutrients in the grain are deposited through manure on the pasture.

Potassium is probably the most important limiting nutrient in legume forage production. Large quantities of potassium are required for optimum vegetative growth of forages. The vegetative part of the plant may contain 2 to 3 percent potassium or more, so harvesting forages removes tremendous quantities of potassium. Under optimal potassium fertility, forage crops, particularly grasses, tend to accumulate higher concentrations of potassium than are required for maximum growth. This is termed luxury consumption and is a problem which contributes to inefficient use of potassium. Potassium fertilizers must be mined, processed, and distributed at the expense of much fossil fuel. The known quantity of potassium-bearing minerals suitable for fertilizer is very large but great savings could be realized by recycling the potassium in animal waste. Potassium, like phosphorus, is not lost if manure deteriorates in storage, except by leaching losses.

It is reasonable to question whether a 2 or 3 century supply of mineable reserves of a nutrient constitutes a "practically unlimited" supply. Unless some rather drastic changes take place, food — and forage — plant production will always need plant nutrients. Recent history has seen very rapid expansion of fertilizer use. We do not know the environmental impact of spreading all that mineral fertilizer on the land over the next few decades. These are good reasons for developing ways to conserve and recycle plant nutrients.

Forage Establishment

It seems likely that if the world demand for grain continues, relatively less forage will be grown on land suitable for grain crop production and the forages on other land will be more intensively managed. This suggests that renovation of forage stands may become increasingly important, since farmers will need to keep these forage areas continuously productive with a minimum of plowing and other major establishment procedures. At present,

establishment technology is better developed than renovation technology.

The importance of interseeding legumes into existing forage grass, from the standpoint of nitrogen supply and forage quality, has already been emphasized. Under certain conditions, there may be advantages to interseeding other crops, such as warm season species, into established stands. Stand management during the first 6-8 weeks after seeding is critical if interseedings are to survive. New equipment and procedures are needed to insure the success of interseeding operations and thus encourage farmers to renovate forage stands more frequently.

Another source of high quality forage that has not been fully exploited in the humid, temperate regions is (a) the use of rye or wheat as cover-crops following silage corn and (b) multiple cropping with other grain or forage crops.

Genetic Improvement of Forages

The benefits of scientific plant breeding are clearly demonstrated by the recent remarkable yield increases in grain crops. Forage crop breeding has also been effective but no individual forage species, with the possible exception of alfalfa, has received nearly the intensive breeding effort as has corn or wheat. As the acreage on which any species is grown increases, the need increases for intensive plant breeding to at least provide safeguards against destructive new disease and insect pests. There are many opportunities for important advances in forage crop production that could be achieved through plant breeding and genetics.

In almost all parts of the humid, temperate region, some summer drought periods occur, during which forage yields decline. Even deep rooted crops like alfalfa produce lower yields during these periods. Yields are reduced in warm, dry periods even when soil moisture supplies are adequate. This suggests that cool season forages are reacting at least as much to high temperature as to moisture deficits during these slump periods. Varietal variations in temperature sensitivity exist in alfalfa (*31*) and presumably in other forages. This variation should be exploited to develop new high temperature-tolerant varieties which will maintain high performance in hot, dry periods.

Persistence within forage species varies considerably. Development of more persistent cultivars is important from the standpoint of reducing seed and other establishment costs and the associated requirement for fossil energy. Persistence is, of course, intimately associated with disease and insect resistance, which must remain important criteria for selection.

The goals of breeding for quality should now include three main thrusts:

1. **Development of cultivars that will retain a high level of digestible energy over longer periods during the season.** This would permit more flexibility in the timing of forage harvests and thus make forage operations more compatible with other farm operations. Late- or non-maturing cultivars could be intentionally left standing in the field beyond the optimum harvest date without serious quantity and quality losses. This could also alleviate some storage problems.

2. **Improving the digestibility of forage plants genetically.** The digestibility of bermudagrass has been increased significantly by breeding efforts (*32*). The result has been a considerable increase in animal productivity. A mutant has also been reported in corn that reduces the lignin percentage in the stover by approximately 40 percent (*33, 34*). The digestibility of the stover was increased approximately 6 percent. Nearly a 30 percent increase in dry matter consumption and a 1/2 kg increase in weight gain was reported when low lignin corn stover was fed to growing beef animals. Recently, Porter et al. (*35*) reported the discovery of similar, chemically-induced mutants in sorghum. These mutants in corn and sorghum are known as brown midrib mutants. If they can be incoporated into lines and hybrids adapted to areas where stover is fed to animals, the productivity of these animals would be greatly increased.

If low lignin mutants exist in corn and sorghum, perhaps they can be discovered in other species as well. Most grasses presumably have similar biochemical pathways for lignin synthesis (*36*). A search should be made to determine if low lignin mutants can be found or induced in cool and warm season, perennial grasses. The breeding and genetic problems associated with such an effort will admittedly be complicated because of the polyploid nature of these grass species. If such mutants can be found, the payoff would be tremendous. Lig-

nin biosynthesis in legumes is somewhat different from grasses, but low lignin mutants may also exist in legumes. The impact of mutants of this nature in perennial grasses or legumes would be much greater than their impact in corn or sorghum.

3. **Eliminating undesirable nutritive characteristics.** Some forages contain antimetabolites that produce subclinical symptoms in animals. These pose a particularly serious problem because the effects show up only in lower reproduction rates, weight gains and milk production, and not in obviously sick or injured animals. The producer may not fully appreciate the magnitude of his losses, unless he can directly compare his operation with others where animals are being fed other forages. The problems associated with tall fescue, a species with excellent agronomic traits but some undesirable nutritive characteristics, illustrate this situation. Forage breeders could help animal production considerably by eliminating some of these antimetabolites through breeding.

As mentioned earlier in this article, active breeding efforts and perhaps a re-evaluation of some breeding procedures should be undertaken to find species and cultivars with relatively low nutrient requirements. This seems particularly important in the future when fertilizers will be more expensive and the energy required to mine, process, and distribute them is likely to be in short supply.

Nitrogen is an integral component of protein, and it is thus impossible to select forage plants with low nitrogen requirements and high protein productivity. Potassium and phosphorus, however, are more catalytic in their metabolic functions in plants, and it is therefore possible that forage plants could be selected for low potassium and phosphorus requirements without necessarily reducing yield potential. Care must be exercised, however, to avoid reducing the phosphorus concentration of the forage below the requirements of the consuming animal. Since research plots are generally well fertilized, it is unlikely that there has been any natural selection pressure for low nutrient requirements of commercial crops in recent decades. Selection of forage varieties with low nutrient requirements would not only conserve mineral fertilizer and energy but would also improve the yield potential of forages grown in less fertile areas. It is interesting to note that, while forages are usually grown on less fertile soils and receive lower applications of fertilizer than grain crops, in research on fields where forage varieties are compared and selected, optimum fertility levels are maintained.

In general, a certain critical mass of breeding effort must be applied to a particular crop before significant advances can be expected. Many potentially useful forage species do not receive this much breeding attention. This is particularly true of the major perennial temperate region forage grasses including bromegrass, timothy, orchardgrass, reed canary grass, and tall fescue plus many of the legumes. In order for forages to make their potential contribution to the world food problem, much more effort must be directed to forage crop breeding.

Harvest and Storage

Forage crops are essentially perishable products. Among horticultural crops, the problem of perishability requires large inputs of labor, machines, sophisticated preservation techniques, and management at harvest time. If such procedures were followed in harvesting forages, higher yields of higher quality products could be achieved. But because the economic returns have not been as great as for other crops, and because the sophisticated harvest and preservation technology has not been available, farmers have not chosen to marshal the resources needed to guarantee high-yield, high-quality forage harvests. In fact, they usually relegate forage harvest management to lower priority than management of several other farm operations.

Energy costs may tend to discourage farmers even further from applying the best harvest technology, because high capacity, energy-requiring machines, expensive storage facilities, drying equipment, etc., are required to assure a high quality product.

The rising cost of grain on the other hand, by indirectly increasing the value of animal products, places a greater economic value on forage so that greater inputs into forage production harvesting and storage are justified. The price of animal products fluctuates widely, however, making livestock feeding operations relatively risky. This tends to discourage inputs into forage production, because even if this aspect of a livestock enterprise is very well managed, the total operation may fail because

of the vagaries of the market for animal products. Thus, forage operations have an additional level of risk, namely that associated with marketing the resulting animal products. That risk is not present in the average grain production operation.

Taken together, these observations suggest high priority forage production technology needs:

- Rapid, high-capacity harvest and storage operations, which would facilitate better timing — a critical factor in forage production.
- Procedures that would reduce the risks of weather damage, field losses and other post-harvest losses of forage quality.
- Development of more efficient labor-saving techniques and machinery.
- Reduction of the use of fossil fuel requirements.
- Design of procedures and machinery that are as simple and inexpensive as possible.

In light of these criteria, it is informative to view two systems of forage crop technology: (a) early forage harvesting and (b) large-package haymaking.

The advantages of harvesting forage early, as pre- or early-bloom stages, have been identified and publicized by forage crop scientists for many years. But in practice most harvest operations are far too late to produce hay or silage of optimum quality. It is estimated that less than 50 percent of the first cutting hay in Indiana is harvested by full-bloom stage for most forage crops. The value of early harvest was clearly demonstrated by Niedermeier, et. al. (*38*). An alfalfa-grass forage harvested at 10 percent bloom fed to dairy cattle produced 11.7 MT of whole milk per year per hectare compared with 10.5 MT of whole milk from forage harvested when the alfalfa-grass mixture was at full bloom. On the basis of these results, if the forage on the 12.7 million hectares of arable land in the humid, temperate regions of the U.S. was harvested at an optimum stage of maturity, this practice alone could result in an additional animal product equivalent to 6 million MT of whole milk. Furthermore, late harvest of the forage delays subsequent harvests, thus reducing the total seasonal yield. The losses in quantity and quality of hay associated with failure to apply this technology in Indiana alone is estimated at over $30 million annually. This occurs in an area where farmers are reasonably well-educated and, in general, are aware of and practice the most advanced

Production of wool and spring lambs can be a profitable enterprise on improved pasture in the humid temperate zone. *Photo by Ohio Agr. Research & Dev. Center.*

technology in other aspects of their operations. As a piece of technology, early cutting meets criteria 4 and 5 and is not inconsistent with 1 and 3. Because of rainfall probabilities in some areas, early cutting may slightly increase the chance of weather damage. Thus, this technology may fail to meet criterion 2.

Large-package haymaking machines are a recent technological development rapidly being accepted by farmers. These machines require little or no more fossil energy than conventional hay harvesting machines and thus are not inconsistent with criterion 4. They meet criteria 1, 2, 3, and 5 very well. They have higher capacity than conventional machines, and thus speed the operation considerably. This in turn reduces weather risks. Because of their speed and the fact that one operator and one machine can effectively harvest the crop and put it in a form in which it is not vulnerable to weather damage, farmers are encouraged to cut hay earlier and sandwich the hay-making operation between other critical farming operations. There has been a very noticeable improvement in the timing of hay operations in Indiana since the advent of the big package haymaking machines. It is conceivable that the reason that big package haymaking has been more rapidly accepted by farmers than the early cutting technology is that the former meets more of the essential criteria listed above. While the economic situation and level of forage crop technology used differ widely over the area discussed in this paper, the criteria are probably generally valid, because all forage producers face the same primary problem -- perishability of their product.

The average haymaking operation in the U.S. is extremely wasteful. Even under ideal drying conditions, a loss of 20-25 percent of the original dry matter is to be expected between cutting and storage. Much of this loss is incurred by mechanical operations such as raking and baling. As long as farmers of the humid, temperate regions use mechanical harvesting methods, they will experience these losses. Some of these field losses, which arise from plant respiration and leaf shatter, are avoided when forages are ensiled. In that case, the material is mechanically handled while moist and therefore less susceptible to leaf shatter. The ensiling process itself, however, occurs at the expense of some feed energy, and unless the material to be ensiled is within a fairly narrow range of moisture content, destructive reactions occur which lower feeding value. Also, fairly expensive harvest and storage facilities are required for silage.

A treatment or procedure by which forage could be safely stored at 30-40 percent moisture would be very advantageous. The material could be mechanically handled before it became dry and brittle, and thereby considerably reduce harvest losses in leaf parts of the forage, which are the highest quality component of the forage. It is estimated that frequently 40 percent or more of the leaves of legumes harvested as hay is lost during the harvesting procedure. Consequently, on a 10 MT/ha alfalfa hay yield, a loss of 40 percent of the leaves would reduce the dry matter and total digestible nutrient yield by 20 percent. If such leaf losses could be reduced worldwide from 40 to 10 percent, then the 55 to 60 million hectares of cultivated forages in the humid, temperate regions of the world could provide some 70 million MT of additional high quality forage, moreover, harvesting hay at these higher moisture levels shortens the required drying time in the field thereby reducing the chances of deterioration caused by adverse weather.

Hay preservatives containing propionic acid or other organic acids and their derivatives have been used for several years but by relatively few farmers. These chemicals are reasonably effective when added in large enough quantities. They make little or no improvement in the original quality of the hay, but do prevent serious losses of that quality. Anhydrous ammonia has been tested as a hay preservative. It is an effective fungicide, adds ammonia which can be used by rumen microorganisms to synthesize protein, and increases the fiber digestibility of hay, presumably by breaking lignin-cellulose bonds (*39*). Further research is needed to develop practical ways of treating moist hay with anhydrous ammonia.

An additional possibility for forage quality improvement is treatment with hydroxides. A 5 to 16 percent increase in the digestibility of low quality hay and crop residues by sodium hydroxide treatment has been reported (*40*, *41*). This chemical treatment apparently reduces the effect of lignin on digestibility (Fig. 1-1). Intake was increased as much as 33 percent and daily weight gains similar to those with corn silage were reported by feeding crop

residues. If simple economical methods of treating forage materials prior to storage or feeding could be developed, the efficiency of animal production from feeding low quality forages and crop residues could be markedly increased.

Dehydration of hay, particularly alfalfa, is practiced in some areas and produces a very high quality product. The common procedure in the past has been to cut and chop the forage and haul it immediately to a dehydrator in which it is dried very quickly, while passing through a large revolving drum. The increasing cost of fossil fuel has caused many dehydrators to change to a system of cutting and windrowing hay in the field, allowing it to wilt before dehydrating it. Under current economic conditions, an efficient dehydration operation requires 1,500 or more hectares of alfalfa and a large expensive dehydrating and processing facility. Unless energy becomes much cheaper, this system is not likely to be used by many producers in the future.

Intensive research is underway to perfect equipment for squeezing the sap from a forage crop, such as alfalfa, so as to produce a residue of about 65 percent moisture and a liquid that is high in soluble protein, vitamins, and minerals. The liquid, perhaps with some modifications, promises to be a useful food or feed for non-ruminant animals. This harvesting procedure would be used mainly for medium-sized or large forage-producing operations. One proposed machine would cut and squeeze the alfalfa, load the residue into one container and the juice into another for transport out of the field. The residue would then be ensiled and the juice fed directly or further processed by coagulation or fermentation.

A more elaborate machine is proposed which would cut and squeeze the material, steam-coagulate the solid matter in the juice, flash-dry the residue to 40 percent moisture, and treat with a preservative. The liquid remaining from the coagulation procedure would be returned to the land and would thus recycle much potassium and phosphorus. The principle advantages of the squeezing operation, from a production standpoint, would be to reduce or eliminate risk of weather damage to the harvested product, virtually eliminate field losses, and encourage timely harvest. If such machines can be designed to be no more expensive and require no more fuel than conventional machines, and if effective and efficient techniques are devised to store and feed the products, this squeezing technique might be adapted fairly rapidly in technologically advanced areas. This technology would likely meet three of the five criteria cited earlier as important characteristics of new forage procedures.

Economic Factors in Forage Production

Even a casual analysis of the existing forage crop production and utilization practices reveals that only a small fraction of the available forage production technology is actually applied by the world's farmers. One possible explanation would be that farmers are generally unaware of the existence of the technology. However, in the humid, temperate forage-producing regions discussed in this paper, most farmers are literate and, in some areas, such as the U.S., many are well-educated. There are active extension programs in these areas. Grain production technology is applied to a high degree in some of the same areas where forages are managed very poorly. These observations suggest that the problem is not primarily one of educating farmers in appropriate forage technology, although continuing and vigorous extension programs will be necessary in order for forage crops to reach their production potential.

Another possible explanation for the lack of application of forage technology is that the available technology is inadequate. It is fair to assume that if great benefits actually accrued from the application of forage technology, most farmers would apply it. The fact that they do not suggests that, under economic conditions exisiting in most humid, temperate regions to date, the average returns from better forage management have not been enough to encourage many farmers to take the risks associated with larger inputs of labor, money, and management in forage production. In some cases, this would require shifting these resources from grain to forage production.

Two relatively recent developments may shift the economic situation so that application of forage technology could become relatively more profitable. One is the dwindling supplies and higher costs of fossil energy and the other is the improved economic situation in developing countries.

From the standpoint of kilocalories of digestible energy produced per kilocalorie of fossil

fuel energy expended (Table 7), forage crop production is apparently much more energy efficient than grain crop production (*41*). Establishment of perennial species is required only once every several years. Forages are usually not cultivated, and in many cases the animal harvests the forage directly without any machine or fossil energy requirement. The fact that the digestible energy of forages is used less efficiently by animals and is therefore less valuable than digestible energy from grain points to the critical need for improved forage utilization techniques. If fossil energy becomes less available and more expensive, fossil-energy-efficient forage systems will be favored.

Table 7. Digestible energy (DE) outputs per unit of fossil energy (FE) inputs into production of various types of feed

Feed	DE/FE Input
Corn grain	2.5
Soybean	2.0
Corn Silage	4.1
Hay	7.5
Grass Silage	8.2
Pasture Herbage	30-115

Source: Item *41* in References and Notes

The gradually improving economic situation in the developing world and the expansion of world agricultural trade has improved the market for grain. The demand for grain has increased the cost of grain to the point where farmers are actively seeking ways to substitute forages for grain in their animal rations and thus lower their feed costs. The quantity of animal product consumed by humans in developing countries is steadily increasing. If demand for grain on the world market continues to increase, farmers who are able to sustain a larger portion of their animal production on forages will realize important economic benefits.

These economic factors will probably do more to encourage the use of sound practices in forage crop production than any increased extension or research programs will do in the near future.

One of the problems associated with forage crop production is that returns to forage operations are often not realized until the forages have been fed to animals and these animals or their products have been marketed. Because of the complexities of forage and livestock oprations the impact of any particular forage management decision on the final outcome of the total operation is difficult for the decision maker to predict. For example, suppose a farmer must decide whether to apply nitrogen fertilizer to a grass pasture in the spring. It is very likely that this practice will increase his herbage yield, but the increased yield may come during the spring flush of growth when the farmer already has too much pasture to utilize efficiently. His decision should be made in the total context of his operation, taking into account not only pasture yields but also total feed supply, feed requirements, storage capacity, costs and prices, availability of labor and machinery, and several other factors. He is unlikely to be able to assess all the available information and do the necessary computation without some technical aid.

This problem could be alleviated by developing a comprehensive but flexible simulation model of forage-animal operations. A farmer with direct or indirect access to such a model could examine the final outcome of alternative management decisions and thus be much better prepared to make correct management judgments. Having such management aid available would encourage farmers to commit more resources to forage operations. Most of the countries in the humid temperate regions have the computer facilities available on which to operate simulation models. Simulation and computer technology has advanced to the point where a great effort to employ them in forage management would now be justified.

Traditionally, forages have been fed to animals on or near the farms on which they are produced. This is because they are generally bulky, do not flow freely, and are otherwise not easily moved. Also, their potential value has been too low to justify much transportation cost. If forages could be more readily and efficiently transported to forage-deficit areas, commercial markets for forages would definitely improve. The result would almost certainly be an increase in the demand for harvested forage products and increased emphasis on advanced production technology.

Over the years, commercial channels have developed for wire- or twine-tied bales weighing 15-50 kilograms. This is virtually the only way that forage crops have moved in commercial channels, except for dehydrated alfalfa

meal, which is used as a supplement in rations of non-ruminant animals. Much labor is involved in loading and unloading bales and the density is such that payloads are not very heavy.

The increased use of big hay packages poses a problem in commercial markets, because, even though big packages lend themselves to high capacity mechanical handling, they are not the right shape for efficient long distance transport. The large round bales are dense but do not stack well on truck beds or railroad cars. Because of their large size, they do not meet the needs of those consumers who have only a few livestock and do not have the specialized equipment to handle and feed the big packages. The stacks made by some large package machines are not dense enough or stable enough for long distance hauling.

New technological developments are required to increase the mobility of hay in market channels. A vigorous hay market seems to be developing in parts of the U.S. Hay is being transported fairly long distances and brings relatively high prices. There is some indication that a world market would develop if practical procedures for shipping overseas were available. These procedures will probably require repackaging or containerizing to provide the density and handling characteristics needed for efficiently transporting the hay long distances. Presumably the development of a world hay market would benefit hay producers in other temperate regions besides the United States.

The standards of quality used to set prices in commercial hay channels are based primarily on visual criteria. While significant quality differences can be distinguished visually, this approach is somewhat subjective and does not discriminate sharply between intermediate grades of hay. Chemical and *in vitro* methods of evaluating the nutritional quality of hay are much more discriminating, but are not routinely available to buyers or sellers of hay.

If better evaluation techniques could be used routinely in hay markets, hay standards would receive much more attention. Price differentials would be established that would make producers more quality conscious. This would almost certainly lead to increased application of existing technology.

Much has been written about the potential of crop residues, particularly corn stalks, as animal feed. Two factors currently hinder the exploitation of this potential. First, conventionally harvested cornstalks are frequently too low in digestibility to meet the maintenance needs of ruminant animals. They must be supplemented with protein, energy, and minerals even to serve the needs of dry, over-wintering breeding stock. Secondly, the largest supplies of crop residues are in the level productive areas where large acreages of grain or grain crops are grown. These are not the centers of breeding livestock concentration.

Two developments will be required in order for crop residues to make their potential contribution to ruminant animal production. First, the feeding quality of the residues must be improved. An increase of 5 to 15 percent in digestibility would make a profound difference in usefulness of these materials. They would then meet the maintenance needs of the breeding stock, at least in terms of energy. Expensive supplementation would not be required. Some of this needed improvement can be achieved by breeding grain crops for lower lignin concentrations, and some will come from chemical and physical treatments that "delignify" the material or otherwise render the fiber more digestible.

The second requirement might come about in two ways. Either the residues must be harvested and handled in such a way as to be very mobile in commercial channels; or, the centers of animal production must shift somewhat to the areas that have large supplies of these residues. If crop residue quality improves to the point where residues become valuable livestock feed, both of these necessary changes will probably come about.

SUMMARY AND CONCLUSIONS

Our view of the future of forage production in the humid, temperate regions and the contribution of forages to the world food problem is based on the following premises.

1. Farmers will adopt modern efficient forage production techniques when and to the extent that it is economically advantageous to do so.

2. The increasing world demand and resulting higher prices of grain, the increased demand for animal protein in the diets of people in developing nations, the water pollution control legislation, and the fossil energy shortage are

all factors which will encourage the application of existing forage technology and the development and application of new technology in the next 25 years.

3. The gradual trend toward higher animal production will foster better human diets, better use of resources that cannot be used directly by humans, and better soil conservation practices.

Research efforts in forage production in the next 25 years should emphasize new practices which:

- Reduce risk in harvest and storage procedures.
- Increase speed of harvest operations.
- Drastically reduce labor requirements.
- Require relatively little fossil energy input.

In terms of the foregoing criteria, or goals, six major research thrusts would be likely to pay off.

1. Forage crop breeding for low lignin concentration and low nutrient requirement.

2. Development of varieties of legumes and perhaps other crops with high capacity for fixing atmospheric nitrogen.

3. Development of chemical and physical treatments to preserve and improve forage nutrition.

4. Perfection of pasture and hay field renovation techniques.

5. Improvement of present harvesting methods toward more energy efficiency, higher capacity, and lower labor requirements.

6. Improved mobility of and price setting mechanisms for forages in commercial markets.

The potential forage and animal productivity of the humid, temperate regions of the world, based on the application of existing and new forage production technology, is summarized in Table 8. On the basis of these figures, the total potential productivity of the 55 million ha of arable land in the humid, temperate regions would be 85 million MT of liveweight animal gain or 1,138 million MT of

Table 8. Summary of estimated annual forage productivity and the potential animal products that could be produced in the humid, temperate regions of the world

Forage production technology	Plant productivity		Animal productivity	
	Dry matter	Digestibility	Liveweight gain	Whole milk
On arable land	*MT/ha*	*Percent*	------ *MT/ha* ------	
Present management	8	55	0.19	3.6
Adequate fertility	10	55	0.24	4.5
Improved varieties and pest control	12	57	0.44	8.1
Timely harvesting	14	60	0.86	12.8
Reduction of harvesting losses	15	65	1.56	20.7
On permanent grazing land				
Present management	2	52	0.02	0.5
Improved fertility	4	54	0.08	1.6
Renovation including interseeding with legumes	5	57	0.17	3.5
Improved grazing management	6	60	0.37	5.5

whole milk —provided the land were adequately managed and the forage properly used. Likewise, the total potential productivity of the 300 million ha of permanent grazing lands would be 111 million MT of liveweight animal gain or 1,650 million MT of whole milk. The animal productivity projections are based on 4.4 Mcal of digestible energy per kg of dry matter and the conversion of this digestible energy into liveweight gain or whole milk as given in Figures 3 and 4. The enormous contribution that forages can make to the human food supply is vividly illustrated by the comparison of the 314 million MT of whole milk produced in 1974 (Table 6) and the potential projection of 2,788 million MT —a 9-fold increase. Such goals of increased food production seem well worth striving for and, equally important, well within reach.

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POTENTIAL OF HUMID AND SUBHUMID RANGELANDS

For Ruminant Animal Production

L. R. HUMPHREYS[1]

Grazing lands of the humid and subhumid tropics feed about 40 percent of the world's ruminant animals. This resource generates meat, milk and fiber for human use; in some agricultural communities it also provides the draft power for crop production and helps to maintain the soil fertility upon which continued crop performance depends.

The ruminant is regarded in some quarters as an inefficient converter of energy and nutrients to human foods (*1*) and a competitor for scarce resources of cropping land which might be used for production of crops needed for human consumption. This view is mistaken in a tropical environment, where high-cost grain feeding systems are rarely used in ruminant production. Ruminants are either grazed on land unsuited to cropping, where their comparative conversion of high-fiber diets is preeminent, or they are run in conjunction with cropping land, consuming residue which would otherwise be wasted.

The potential of land in these regions for ruminant production rests upon its further conversion from woodland and forest, and upon the removal of some limitations to production which are intrinsic to current management systems. The technological basis for transformation is well advanced in a few tropical regions; in most areas insufficient adaptive research has been carried out to provide workable strategies for increasing production which are in tune with local aspirations and social structures.

Efficiency of ruminant production may be altered by changing the botanical composition of grazing lands, by altering the environment in which plants grow, or by increasing the efficiency of animal use of grasslands.

[1] L.R. Humphreys is Reader in Agronomy at the University of Queensland, St. Lucia, 4067, Australia.

RESOURCE BASE FOR RUMINANT PRODUCTION

Tropical Grazing Lands

Tropical grazing lands are considered to extend to about lat. 30° on either side of the equator; vegetational affinities justify this viewpoint (*2*). The boundary between the semi-arid zone and the subhumid zone is approximated to the Koppen climatic limit (*3*) of BSh tropical and subtropical semi-arid steppe. China and the United States are not discussed.

The area of tropical grazing lands constitutes about 28 percent of the world's land surface (Table 1). The categories of land use in this table are difficult to interpret because of the variable designation of much grazing land as woodland or as other land. Extensive areas of permanent pasture in Africa (345 million hectares) and South America (198 million ha), and the high proportion of cultivated land (30 percent) in Asia are noteworthy. The dominant grasses are members of the tribes of *Paniceae* and *Andropogoneae*, which reach their maximum floristic expression in the western and eastern hemispheres respectively. Increasing numbers of the tribe *Eragrosteae* appear in response to increasing aridity, while the presence of *Festuceae* indicates decreasing temperature (*5*). The following papers describe grassland communities: (*6*, *7*) for global coverage; (*8*, *9*) for Africa; (*10*, *11*, *12*) for Central and Southern America; (*13*, *14*) for Asia; and (*15*) for Australia.

There are communication problems in the use of the terms "grassland" and "savannah;" even the generic "grazing lands" is not entirely satisfactory for this paper, since some forages are cut rather than grazed. It is doubtful if true grassland or savannah (in which herbage dominates and trees or shrubs are rare) occurs as a climax formation in the humid and subhumid

Table 1 — Land area components of the humid and subhumid tropics

Region	Permanent pastures and land meadows	Forests and woodlands	Cultivated	Other lands	Total land area
			Million hectares		
Africa	345	521	112	326	1,287
Central America	57	51	30	57	193
South America	198	814	44	318	1,363
Asia	29	341	216	138	721
Oceania	26	160	2	28	217
Subtotal	655	1,887	404	867	3,781
World	2,992	4,035	1,473	4,899	13,399

Source: (*4*)

tropics, except under special edaphic conditions such as salinity or impeded drainage. Grasslands are otherwise developed in response to disturbances such as clearing, cultivation, fire, and grazing. In this paper, however, the grazing lands are categorized as swamp grasslands, watershed grasslands, savannah woodlands, grazing lands associated with cropping and settlement and montane grasslands. Cultivated tropical grasslands (*16*) are those in which the natural vegetation is wholly replaced by planted forage species.

Swamp Grasslands

Swamp grasslands are a valuable resource, particularly in the monsoon tropics where they extend the season of green forage availability. In Thailand they grade from sites where deep water occurs for most of the year, and *Hymenachne pseudo-interrupta* is grazed by swimming buffaloes, to drier sites with impeded drainage where *Echinochloa stagnina* is prominent. *Paspalum distichum* occurs in more saline sites.

In the Northern Territory of Australia, the coastal plains are dominated by *Oryza rufipogon* and *Ericcharis* sp. on the wetter sites, and by *Eriachne burkittii* and *Themeda australis* where flooding occurs for 3 to 4 months of the year (*17*). *Oryza australiensis* predominates in north Queensland coastal swamps, and *Sporobolus virginicus* occurs in saline places. *Phragmites karka* occurs in high elevation depressions in Papua-New Guinea. *Leersia Hexandra* is well-used throughout the swamps of Central and South America; in Mexico it occurs with coarser species such as the tall *Paspalum fasciculatum* and various sedges. The Bajo Llano of Venezuela and Colombia are significant grazing lands, and in the eastern llano *Aristida*, *Axonopus anceps*, and the unpalatable *Trachypogon vestitus* are found.

In southern Sudan seasonal swamps bear the valuable *Echinochloa stagnina*, together with *E. pyramidalis* and *Oryza barthii*. The *Cyperus papyrus* swamps are used for thatch, but *L. hexandra* also occurs. The mbuga grasslands of Tanzania contain species of *Setaria*, *Chrysopogon*, *Panicum*, *Eriochloa*, *Ischaemum* and *Sehima* (*18*). In West Africa (*6*) *Echinochloa stagnina*, *Panicum laetum*, *Fimbristylis exilis* and *Andropogon gayanus* appear in areas of impeded drainage. Rattray (*9*) refers to undifferentiated flood plain grassland, containing *Loudetia* and *Tristachya* on the Zambesi, and *Jardinea congoensis* in the Congo.

Other forms of edaphic grassland climax develop in the humid and subhumid tropics, for example, on shallow soils in Rio Grande Do Sul.

Watershed Grasslands

Treeless uplands occur extensively as a grassland disclimax in the humid and subhumid tropics. In many regions they represent the endpoint of a shifting slash-and-burn cultivation system, in which increasing population pressure or some other factor has led to an exploitative short-term forest fallow. Increasing frequency of fires and cultivation, and decreasing soil fertility leads to the dominance of a grass cover.

In Asia many millions of hectares of watershed grasslands occur in which the tall rhizomatous *Imperata cylindrica* predominates; these are found in India, Sri Lanka, northern Thailand, Vietnam, Laos, Indonesia (especially Sumatra and Sulawesi), Malaysia, Papua-New Guinea and the Philippines. *Imperata* grasslands are also found in Zaire and the Congo, Uganda, Sierre Leone and Madagascar. In Fiji and the Solomon Islands *Pennisetum polystachyon* or *Dichanthium caricosum* are more successful invaders. In Central America, for example in Panama, the low-fertility demanding naturalized *Hyparrhenia rufa* forms a fire disclimax.

These covers are stable under frequent firing and light grazing pressure, but are not tolerant of heavy grazing. For example, in New Guinea *Imperata* may be displaced by *Digitaria insularis*, *Sida cordifolia* and *S. rhombifolia*, or by shorter grasses such as *Paspalum conjugatum*. In the Philippines, the tall *Imperata* or *Saccharum spontaneum* are replaced under heavy grazing by the sod-forming *Axonopus compressus*. In Colombia *H. rufa* is displaced by *P. virgatum* under severe grazing pressure.

Savannah Woodlands

Little grazing is available in the forests of the humid and subhumid tropics; forest margins and disturbed situations are used if accessible to ruminants. There are many types of woodland formation with a well-developed herbage understorey, in which tree foliage does not form a closed canopy. A sparse tree or shrub density may result from human clearing activities, producing a formation which grades into savannah.

On the sandy uplands of northeast Thailand and of southern Laos, open dipterocarp woodland has a herbage cover of the erect, rhizomatous *Arundinaria ciliata* or *A. pusilla*. Increased grazing pressure associated with the extension of settlement leads to the invasion of shorter grasses such as *Chrysopogon aciculatus*, *Dactyloctenium aegyptium*, *Brachiaria miliiformis*, unpalatable legumes such as *Tephrosia* cf. *wallichii*, and the weeds *Eupatorium odoratum* and *Sida rhombifolia* (*19*). The valuable timber species *Shorea obtusa* and *Xylia kerrii* are eaten in the seedling stage.

In northern Australia Moore (*15*) designates subhumid *Eucalyptus* woodland with tall bunch grasses as the major formation. *Heteropogon contortus*, *Themeda australis*, *Sorghum plumosum* and the annual *Sorghum intrans* are the characteristic species. In Queensland *Bothriochloa bladhii* and *Dichanthium* are significant components. *T. australis* decreases with grazing and firing, while *B. decipiens* and *Chloris divaricata* increase.

The Llanos Orientales of Colombia (*11*) contain savannahs with forest components, characterized by *Melinis minutiflora*, *Paspalum carinatum*, *Andropogon bicornis* and *Trachypogon ligularis/P. carinatum*. The Alto Llanos of Venezuela has been divided by Blydenstein (*20*) into wet grassland in gallery forest, dominated by *Paspalum*, low Llano, palmares, morichales, and high Llano *Trachypogon* savannah. The vast cerrado of the central Brazilian plateau contains diverse elements, ranging from savannah to forest, with woodland savannah dominant. Grass constituents include *Andropogon lateralis*, *A. condensatus*, *Axonopus affinis*, *Aristida*, *Hyparrhenia rufa*, and *Tristachya chrysothrix*. Leguminous trees (e.g. *Bauhinia*) and herbage (e.g. *Stylosanthes viscosa*) are common. Pine savannahs occur in Costa Rica (*21*).

There are a number of woodland formations with well developed grass constituents on the African continent. Covers designated by Rattray (*9*) as *Hyparrhenia* or *Pennisetum* dominant are within the scope of this paper, while *Cenchrus* and *Eragrostis* are clearly semi-arid; *Andropogon gayanus* is often on the boundary of the subhumid zone. Shrub and tree foliage is a significant component of the ruminant diet (*22*), especially during dry periods; edible species of *Combretum*, *Terminalia*, *Bauhinia*, *Acacia*, *Grewia*, *Baphia*, and *Griffonia* should not be regarded merely as factors inimical to herbage growth.

Cropping Lands

Intensively cropped areas often contain a high ruminant density, especially in Asia. For example, on the island of Bali, cattle density increases from 0.23/ha in the district of Jembrana, where pastures are evident, to 1.0/ha in the irrigated rice district of Gianyar. Ruminants provide the draft power for cropping operations, surplus animals being sold or fattened. The animals are fed on crop residues, for example, rice straw, maize stover, byproducts of

agricultural processing, road-side pastures, common lands around areas of settlement, land unsuited to cropping contiguous to cultivation areas, edible hedges and volunteer species growing on fallow land. Rarely (except in India and parts of Africa) are they fed crops grown specifically for their consumption. In the monsoon tropics the period of most acute forage deficiency may be the main growing season, when crop land is inaccessible to animals, especially if adjacent savannah or savannah woodland grazing is unavailable. Grazing of lands planted to plantation crops such as coconuts is of great contemporary interest.

Ruminants housed at night or fed cut forage may create a fertility gradient from uncropped to cropped land. In West Africa, grain farmers encourage the seasonal grazing of Fulani cattle on their cropping lands to convert crop residues and volunteer growth to animal manure.

Montane Grasslands

Temperate montane grasslands are of especial significance in Central Africa (*23*) and South America (*5*). Their area is small, but they have a potential for dairy production not attached to other areas.

Ruminant production from the Andean grazing lands is low. In Peru and Ecuador they consist of inferior species of *Calamagrostis*, *Deyeuxia*, *Distichlis*, *Festuca*, *Muehlenbergia*, *Poa* and *Stipa ichu*, a bunch grass with stiff involute leaves. Alpine meadows used for sheep occur in Colombia above 3,000 m and mainly comprise *Ariachne pulvinata* and *S. ichu;* there is a transitional zone to more sub-tropical flora at 2,000 m, with many species of *Andropogon*, *Axonopus*, *Panicum*, *Pennisetum* and *Paspalum* growing at this elevation and below. Montane areas are also found in Venezuela, Costa Rica, Guatemala, and in Mexico, where species of *Agrostis*, *Andropogon*, *Bouteloua*, *Poa* and *Trisetum* predominate

The most productive natural highland pastures in Kenya, Tanzania and Ethiopia are based on *Pennisetum clandestinum* growing on deep red latosols. *P. schimperi*, *P. catabense* and *P. villosum* occur on poorer soils. Rattray (*9*) designates *Exotheca abyssinica* as a characteristic montane grass cover in Sudan, Uganda, and Malawi, and *Pentaschistis perrieri* in Madagascar. Montane grasslands also occur in northern India, the Nilgiris of southern India, Sri Lanka, Laos, Indonesia and New Guinea.

Animal Population and Output

The humid and subhumid tropical grazing lands contain about 40, 60, 11 and 37 percent of the world's cattle, buffaloes, sheep and goats respectively (Table 2). Within these regions sheep and, to a lesser extent, goats are most abundant in the drier subhumid zones, while buffaloes mainly occur in the humid lowlands. The estimate of 194 million cattle in Asia is inflated by the inclusion of 142 million from India, many of which are non-productive sacred animals. Mexico, Cuba, Colombia, Venezuela, Brazil and Paraguay have the largest cattle populations in Central and Southern America, while Ethiopia, Kenya, Tanzania, Nigeria and Madagascar are pre-eminent in this respect in Africa. Buffaloes occur mainly in Asia; minor populations are in Brazil and Trinidad. Sheep and goats probably contribute no more than 5 percent of the grazing pressure on these lands.

Table 2 — Average ruminant population of the humid and subhumid tropics, 1969-1973

Region	Cattle	Buffaloes	Sheep	Goats
		Million		
Africa	86		34	53
Central America	35		3	6
South America	134		44	21
Asia	194	75	30	62
Oceania	6			
Subtotal	456	75	111	142
World	1,132	126	1,057	387

Source: (*4*)

Humid and subhumid tropical grazing lands contribute about 15, 11 and 12 percent of the world's beef, mutton and milk production respectively (Table 3). These figures considered in relation to the ruminant population estimates indicate the low product output per animal of the tropics relative to the temperate zone. Within the tropics, output per animal for both meat and milk are lower in Africa and Asia than in Oceania and Central and South America. Total meat production is dominated by South American countries, mutton and lamb production being less well developed than beef and veal re-

Table 3 — Average annual meat and milk production from ruminants in the humid and subhumid tropics, 1969-1973

Region	Beef and Veal	Mutton and lamb	Milk
	Million metric tons		
Africa	1.08	0.28	5.16
Central America	0.91	0.02	5.37
South America	2.99	0.11	12.24
Asia	0.91	0.32	22.97
Oceania	0.23	—	0.84
Subtotal	6.11	0.74	46.58
World	39.47	6.95	403.58

Source: (*4*)

lative to Africa and Asia. Milk production is greatest from Asia, the buffaloes and cows of India contributing the bulk of production. Goat milk production is a significant factor in India, Bangladesh, and Mexico.

Current Limitations to Ruminant Production

What determines the level of animal production? The amount of pasture grown, the proportion of this which is ingested, and the amount of animal output produced per unit of feed eaten — these are the three component systems whose product determines animal output per unit area. These systems are interdependent; for example, level of consumption may influence pasture growth rate and nutritive value, and evaluation must be made in terms of the final criteria of level and stability of animal output.

Plant production depends on the genetic capacity of the individuals composing grazing land communities for growth, and on the availability of environmental growth factors. Tropical grasses possess the C_4 dicarboxylic acid photosynthetic pathway, which is more efficient than the C_3 phosphoglyceric acid pathway of the temperate pasture species and the tropical legumes (*24*), and are more responsive to higher levels of radiation. High growth rates are also associated with more efficient use of water (*25*) and of nutrients. The evolution of plant communities also leads to fitness, which implies tolerance of the particular environmental stresses which occur, or mechanisms of escaping stress. Adaptation has occurred to extremes of temperature, fire, shading, excesses and deficiencies of water and of nutrients, and to biotic factors such as grazing, pests and pathogens.

Levels of radiation are high in the sub-tropics, and are higher in the equatorial than in the temperate zone. Temperature and the seasonal variation of temperature limit growth less than in the temperate zone, but temperature regimens are nevertheless limiting for vast areas of sub-tropical and montane grasslands; they may even be a minor limitation in low-land equatorial areas (*26*). Rainfall and soil moisture storage capacity are powerful growth determinants (*27*), but the primary limitation on the growth of tropical pastures, which are usually situated on soils unsuited to cropping, is the supply of mineral nutrients. Many tropical soils are acid, high in aluminum and manganese, low in base exchange capacity, and grossly deficient in essential elements. Cultivated tropical grasses growing without limitation of nutrients or moisture yield in the range 30 to 86 T dry matter of shoots ha/yr; the normal yield range of natural pastures is 2 to 6 T/ha in the humid tropics and 1 to 4 T/ha in the subhumid tropics.

The proportion of plant material consumed by ruminants is determined first by the animal density in relation to forage supply, and the extent of competition between animals. Less of the energy flow (*28*) is channelled to plant litter and to secondary decomposers if ruminant utilization is high. This is modified by continuity of forage supply; in environments with pronounced seasonal growth rhythms, animal density will adjust to the capacity of the pasture to support animals during periods of scarcity. Consumption also depends upon accessibility of pasture. The availability of stock water for example, restricts the use of *Arundinaria* pastures in northeast Thailand and central Laos. Other constraints such as security needs limit pasture grazing. Fire reduces the amount of forage offered to animals, at least instantaneously. The proportion of trees and other plants which are unacceptable to stock is modified by animal species preferences; multiple animal use of grasslands leads to more complete

consumption. Game ranching is an alternative source of meat production (*29*). Finally, the nutrient balance and other parameters of the forage determine voluntary intake, and there is more genetic variation in this factor in tropical forages than in percent digestibility (*30*).

Conversion of ingested material to animal output (meat, milk, fiber or work) also depends upon nutritive value; digestibility values for natural tropical grasslands are usually only in the range 40 to 60 percent. Low rates of reproductive efficiency, animal survival and of liveweight gain or milk production mean that most of the energy obtained goes to maintenance of body tissues rather than to product output. Small reductions in age at mating and in age at slaughter lead to quite large gains in overall herd output. Efficiency of conversion also depends upon the effects of environmental stresses upon animals, the genetic capacity of the animals to respond to the level of nutrients available, and upon animal health and management.

APPROACHES TO OVERCOMING PRODUCTION LIMITATIONS

All strategies for increasing ruminant output from tropical grazing lands involve changing either the plants which grow there, the environment in which they grow, or the efficiency with which animals use the plants grown.

Removal of Trees

Environmental growth factors may be diverted from the production of tree fiber to the synthesis of pasture for ruminant utilization. Thinning of woodlands is an attractive option for increasing animal production, especially in areas where rural labor is under-employed. In some African territories, tree removal is a prerequisite for domestic animal production, since the environment must be made unfavorable for the *Glossinia* sp. flies which carry trypanosomes.

Herbage growth is negatively related to tree density in a curvilinear fashion, and a transition sigmoid function has been widely used to describe this production relationship (*31*). Herbage biomass in southern Queensland *Eucalyptus populnea* woodland varied from 820 kg in untreated areas to 1,540 kg in ring-barked areas to 2,600 kg/ha where the trees were poisoned. A minimum density of 6 trees/ha was required for near-maximum herbage production; shrubs were less influential. *Brachystegia* woodland in Rhodesia gave an average annual yield of pastures dominated by *Digitaria* sp. and *Hyparrhenia filipendula* of 360 kg/ha; pasture yield was 1460 kg/ha after the trees were ring-barked (*32*).

In the Nigerian northern Guinea savannah, it has been estimated (*33*) that clearing of the shrub increases carrying capacity from 0.18 to 0.36 beasts/ha. Poisoning an *E. melanophloia* woodland in central Queensland increased liveweight gain of *Heteropogon* grassland from 14 kg/ha to a maximum of 35 kg/ha (*34*). *Heteropogon-Bothriochloa bladhii* pastures oversown with *S. humilis* in an *E. crebra* woodland in north Queensland averaged 19 kg LWG/ha/yr in the first 4 years of an experiment, relative to 43 kg/ha/yr in cleared treatments (*35*); this difference was subsequently reduced in wetter years.

These examples indicate the large increases in beef production which are feasible through tree removal. The simple technique of ring-barking gives slower grass development than poisoning trees, but labor and a light axe are the only inputs required. Considerable advances have been made in tree injection techniques, and picloram and 2,4,5-T are effective on a wide spectrum of tree species (*36*). Woodland composed of fire-intolerant species may be thinned by manipulating grazing management to accumulate fuel for a hot fire. Land clearing with bulldozers is more appropriate to a cultivated pasture development.

Thinning of some woodland communities does not necessarily result in greater herbage yields. The original tree species may regenerate in greater numbers, or the succession may be displaced to the dominance of invading shrub species. In southern Queensland, the ingress of *Acacia* and *Cassia* spp. is greater on sandy soils than on heavy soils, and hence thinning of woodlands on heavy soils has priority. Heavy grazing with sheep, or a combination of burning and grazing at low stocking rates with cattle will control the regeneration of many woody plants (e.g. *37*, *38*) and sufficient stock control should be available to provide stock concentration on problem areas, as these arise. Some species need inputs of chemicals or ne-

chanical treatment. Trees are required for stock shade, shelter and browse, and should not be removed from steep slopes, watercourses, or soils subject to land-slips.

In many tropical areas, a shifting cultivation system of "slash-and-burn" agriculture leaves the land surface for long periods under regenerated jungle after a cropping phase. The possibility of using a grazed legume dominant pasture phase in place of a tree fallow requires further study; promising indications have been obtained in Laos from the oversowing of *S. guyanensis* in upland rice crops planted in the ashes of hand-cleared rain-forest (*39*).

Legume Overseeding

Adding legumes to existing pastures offers more scope for realizing livestock production potential than any other single practice. The growth of cattle has been positively related to the legume content of tropical pastures (*40*). Legumes are expected to improve the nutritive value of the diet, maintaining animals in positive nitrogen balance and enabling them to ingest larger quantities of low nitrogen high fiber grass, and to contribute to the nitrogen economy of the soil-plant system, increasing the nitrogen content of companion grasses and maintaining or raising the soil fertility upon which continued production depends.

The selection, breeding and evaluation of superior legume cultivars continue, but plants are available for most ecological niches. In the humid tropics *Stylosanthes guyanensis* has been oversown in derived grasslands dominated by *Imperata* in Malaysia (*41*), Queensland (*42*), Uganda (*43*), Congo (*44*), and Nigeria (*45*), in *Pennisetum polystachon* in the Solomon Islands and in *Hyparrhenia* grasslands in Zambia (*46*) and Nigeria (*47*); *Centrosema pubescens* has been used to a lesser extent. *Macroptilium lathyroides* is sown in swamp grasslands. In less humid areas and in well drained situations *M. atropurpureum* cv. Siratro is successful. It has been sown in *Heteropogon* (*34, 48*) and in *Imperata* (*49*) grasslands of Queensland, in *Pennisetum polystachon* grasslands in Fiji (*50*), and in many other situations. *Desmodium intortum* and *D. uncinatum* are adapted to the humid sub-tropics and montane tropics, and have been successfully overseeded in *Hyparrhenia* in western Kenya; *Trifolium semipilosum* and *T. repens* also have a role in the cooler of these regions. In subhumid areas with significant cool season rains, *Medicago sativa* has been sown in *Heteropogon* (*51*) and in *Dichanthium-Stipa* (*52*); annual *Medicago* spp. are a further alternative.

The most widespread sowings have been made with the annual *S. humilis* in the subhumid tropics, and these have been most successful on sandy upland sites. For example, 25,000 ha were overseeded in the Northern Territory of Australia in 1967-69 (*53*), and the plant is now present in 0.53 M ha of Queensland (*54*). It has become naturalized in parts of South-East Asia, e.g. on *Heteropogon* hillsides in eastern Bali, on roadsides, village pastures, and in *Arundinaria* in north-eastern Thailand (*55*), in some African territories, e.g. Tanzania, Upper Volta, and in south Florida (*56*). The free-seeding perennial *S. hamata*, which provides a longer period of green leaf availability, has shown promise in areas where *S. humilis* is well adapted (*57*). The low-growing *S. guyanensis* cv. Oxley is suited to sub-coastal granitic sands in southern Queensland (*58*).

The acceptance of overseeding by farming communities is greater if broadcast seed is the only input, and if no modifications to existing management are required; this is sometimes feasible. Preparation of the area for sowing usually requires that a check be given to the natural grassland which will reduce its canopy and vigor and enable some broadcast seed to fall on soil. This is achieved by heavy grazing, cutting, burning, or cultivation. An early wet-season burn effectively checks annual *Sorghum* grassland in northern Australia (*59*). Removal of *Imperata* or *Hyparrhenia* for thatch gives a favorable sowing situation. Cultivation or sod-seeding increases percent establishment and seedling vigor, and is indicated for *M. sativa* and *T. repens*. Excessive slope, surface stone or fallen logs preclude cultivation, but seed-bed preparation using herbicides has not been accepted for overseeding tropical grasslands, despite its biological feasibility (e.g. *60*). Minimal cultivation and seeding of one quarter of the area on the contour has been successful with well-adapted plants capable of rapid invasion of the adjacent grassland, for example in central Queensland using *S. humilis* (*61*).

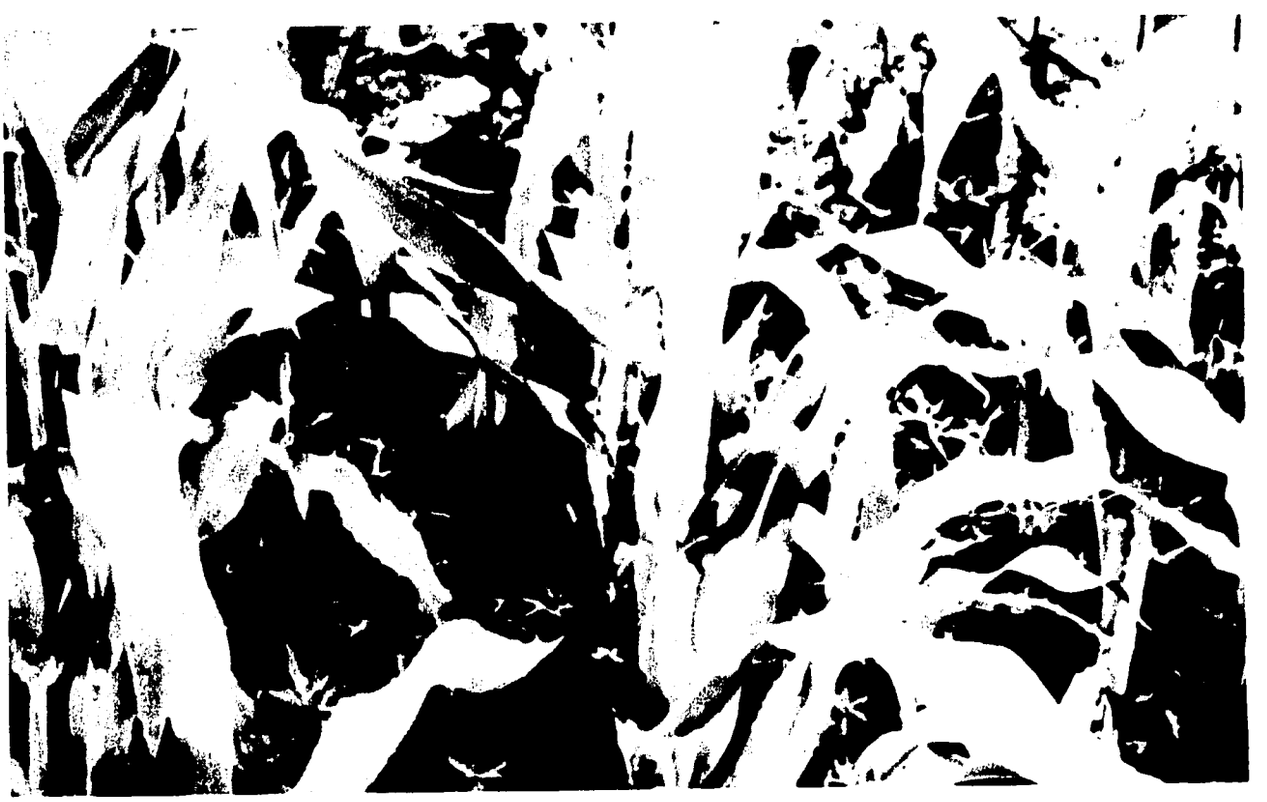
S. guyanensis, Macroptilium atropurpureum, S. humilis, S. hamata cv. Verano and *M. lathyroides* form an effective symbiosis with indigenous rhizobia, and rhizobial strains select-

ea for superior nitrogen fixation have not been sufficiently incursive to benefit these species in field sowings. The more strain-specific *Leucaena latisiligua S., guyanensis* cv. Oxley, and, to a lesser extent, *C. pubescens*, *D. intortum* and *D. uncinatum* may require inoculation. Rhizobial survival is poor on uncovered seed, and pelleting using an adhesive and finely ground rock phosphate is indicated for the alkali-producing tropical rhizobia; *L. leucocephala* and the temperate legumes e.g. *T. repens*, *M. sativa* benefit from lime-pelleting since their rhizobia are acid-producing (*62*). Reduction of hard-seededness by mechanical abrasion or hot water treatment is often indicated, especially with hand-harvested seed. The requirement for fertilizer to promote an adequate symbiosis is discussed later.

Grazing pressure must be lenient after sowing trailing legumes such as *M. atropurpureum*, *C. pubescens* or *D. intortum*, since these are intolerant of heavy grazing and avoid shading by overtopping their supporting companion grasses. The low-growing *S. humilis* and *S. hamata* benefit from continued heavy grazing in situations where vigorous, tall, companion grasses would otherwise shade them; the grasses are selectively eaten while green. Grazing *S. humilis* overseeded into low-growing seral grasses in north-east Thailand is not necessary (*63*). Management of *S. guyanensis* requires study; grazing stimulates seedling branching, which assists perennation under grazing, but the absence of grazing usually gives legume dominance and greater nitrogen accretion in the first year. Choice of species for overseeding may be dictated by existing grazing pressure, e.g. *S. humilis* close to settlement and *M. atropurpureum* in more distant forest margins.

Undersowing Crops with Legumes

The greatest scope for overseeding legumes lies in the cleared watershed savannahs, the more open savannah woodlands, and the heavily grazed roadsides and communal grazing lands adjacent to settlements. Attention should also be given to the cropping lands, and to the feasibility of growing forage legumes with companion crops. This practice can lead to the more efficient utilization of low-nitrogen, high fiber crop residues and to the maintenance of body condition of draft animals used for ploughing at the end of the dry season. The undersown



Townsville stylo grass growing under maize in Bali. *Photo by L. R. Humphreys.*

legume may provide continuity of feed supply in the dry season, regenerating or being re-sown in the next cropping season, or it may form the base for a longer pasture phase in the cropping rotation. Where animals graze on both crop stubbles and on adjacent land, the ingestion of hard legume seed on the cropped land provides a mechanism for seed transfer to other grazing areas.

Beneficial effects on crop production are expected through weed suppression, the more efficient return of crop residues, and the nitrogen accretion due to the legume; for example, in northeast Thailand, nitrogen yield of plant tops was 33 kg/ha from upland rice monoculture, or 96 kg/ha from a combination of rice and *S. guyanensis* (*64*). Exploitative cropping of sandy upland soils is in some tropical situations restricting the choice of crops available, and there is a shift in emphasis to low-fertility tolerant crops such as cassava. On the other hand, competition for light, nutrients or water may decrease crop yields in some pasture undersowing situations, and the balance of competition should be controlled to meet the particular crop and livestock production objectives applicable. Crop yield can be adjusted by manipulating crop and pasture density, crop maturity type, time of sowing pasture in relation to crop sowing time, and fertilizer application. For example, an undersowing system which provided about 3,000 kg/ha *S. guyanensis* at the end of the wet season, with at worst 10 percent reduction in upland rice grain yield (and usually no reduction in grain or straw yield) might be expected from 45 rice plants per m^2 and 25 *S. guyanensis* per m^2, with *S. guyanensis* sown 10 days after sowing an early rice cultivar with no nitrogenous fertilizer (*64*).

Successful companion cropping with forage legumes has been reported for sorghum and *S. humilis* in the Northern Territory of Australia (*65*), for maize and various legumes in Malawi (*66*), Kenya (*67*) and in Tanzania (*68*), and for other combinations. The use of legumes undersown in tree crops is a significant factor in increasing the animal product from a pasture-tree crop system and introduces a beneficial factor to the tree crop component (*69*).

Promotion of Desirable Disclimax

Control of the reversion of induced grassland to trees and shrubs has been discussed. It is equally important to prevent degradation of grassland by over-grazing to inedible weeds or bare ground; in addition to the immediate loss of grazing, watershed characteristics may be impaired and the resource base for production eroded. Ecosystem stability must be maintained, and environmental protection requires a knowledge of the plant species indicative of over-grazing (*70*). Controversy exists as to the most desirable successional stage which provides both ecosystem stability and optimum animal output. Many South African and North American grassland scientists have advocated grassland management systems directed to maintaining a sward containing many plants high up the successional scale. However, this is accompanied by low mineral availability (*71*), and in some grassland types seral stages are more productive. Many of the improved tropical grass cultivars are drawn from the genera *Panicum*, *Urochloa*, *Paspalum* and *Cenchrus* and predominant under conditions of better mineral availability in the seral stages. On the other hand, ruderals and annual grasses provide poorer continuity of forage supply.

Range condition assessments have, in most environments, qualitative and subjective bases; their quantification has been rarely validated in terms of sustained animal output. The conceptual base of "non-selective grazing" has disastrous implications for animal production, since selectivity between species and between plant parts is necessary if animals grazing tropical grasslands are to give adequate productive performance. The application of rotational grazing systems directed to the maintenance of a favorite botanical composition can reduce reproductive efficiency (*72*), and liveweight gain; alternatively animal performance may be independent of stocking method, and the added expenses of herding and fencing are wasted. Control of stocking rate is a better approach to the maintenance of a desirable disclimax stage, but stocking rate experiments are needed in more tropical environments before sound recommendations can be made which meet both botanical and animal performance criteria.

Fertilizer Responses

Mineral and moisture supply are two aspects of the pasture environment which are susceptible to modification. The application of fertilizer on natural grasslands is biologically in-

efficient, since cultivated forages have usually been selected for their responsiveness to an improved nutrient supply, and provide superior opportunity for use of this input (e.g. *73*). Fertilizer application to natural grassland has not been accepted by farmers of any region in the tropics. On the other hand, the growth and nitrogen fixation of legumes overseeded in natural grasslands may depend upon the rectification of mineral nutrient deficiencies, and may be economically attractive in some circumstances. Certainly the stimulation of nitrogen-fixation by legumes is a more attractive option than the use of nitrogenous fertilizer on natural grassland. Recent discoveries of the role of *Spirillum* in nitrogen fixation in grass roots are exciting interest.

Legumes are sought which can extract nutrients from soils of low mineral content, which tolerate mineral excesses, and which utilize the minerals extracted efficiently in growth. *S. humilis* and *S. guyanensis* have good reputations in this respect, and are found on many soil types. *S. humilis* has a superior capacity to extract phosphorus at low levels of supply (*74*); in some tropical legumes this may be associated with the growth of vesicular-arbuscular mycorrhiza on the roots (*75*). Many tropical pasture legumes tolerate high levels of soil acidity; calcium is extracted at low levels of supply by *S. bojeri* and *C. pubescens* (*76*), and *S. humilis*, *C. pubescens*, *Lotononis bainesii* and *D. uncinatum* are more tolerant of high levels of manganese than *Glycine wightii*, *L. latisiligua* or temperate legumes such as *Medicago sativa* (*77*). In some circumstances liming may have negative effects, inducing deficiencies of zinc or copper. The high phosphorus utilization quotient of the annual *S. humilis* (which may reach 1,600 when mature) is associated with efficient export of nutrients from senescing leaves and stems to seed (*78*); while this factor operates to give good levels of plant growth and regeneration, it may lead to phosphorus contents which are suboptimal for animal production. The successful adaptation of *S. humilis* on unfertilized grey podzolics and on red-yellow latosols in northeast Thailand is indicative of its tolerance of low fertility; in this subhumid region maximum *S. humilis* growth occurs when applied phosphate has raised available soil phosphorus (sodium bicarbonate method) to only 6 ppm (*79*).

In some situations, legume overseeding is unsuccessful unless the soil mineral supply is amended; e.g. *Desmodium* overseeding of *Hyparrhenia* in western Kenya (*80*) and of *Imperata* in north Thailand (*81*) requires superphosphate. The most common deficiencies are the macro-nutrients phosphorus, sulphur and potassium and the micronutrients molybdenum, zinc and copper. On low nitrogen soils the legume may respond better to fertilizer application than the companion grasses, depending on species, and the promotion of a more effective rhizobial symbiosis may increase legume nitrogen content (e.g. *82*). As soil nitrogen accretion occurs, nitrophilous grasses with the C_4 photosynthetic pathway and higher growth rates than the legumes then compete for soil nitrogen more effectively, and may become dominant. A cyclic increase of *S. humilis* has occurred as soil nitrogen diminishes (*83*). This classical explanation of legume-grass dynamics is unsatisfactory in some circumstances; for example, successful grass competition for applied phosphorus has occurred under conditions of low nitrogen supply (*84*, *85*). A combination of fertilizer application and increased stocking rate has led to the invasion of annual grasses and weeds in *S. humilis* pastures in north Queensland and the Northern Territory of Australia, but *Heteropogon contortus* has been maintained in these circumstances in central Queensland (*86*), where the greater cool-season rainfall may favor the persistence of this perennial grass.

Decisions about the profitability of fertilizer use on natural grassland overseeded with legumes require an estimate of response in terms of animal product; there are few studies of this type and in some the fertilizer effect is confounded with overseeding or stocking rate effects. In Uganda Zebu steers grazing at 4.7 beasts/ha produced 474 and 279 kg/ha/yr liveweight gain (LWG) respectively on *Hyparrhenia* grassland oversown with *S. guyanensis* with or without superphosphate application (*43*). In central Queensland, Hereford steers grazing at 0.95 and 0.74/ha on fertilized P, K, S, Ca, Mo and unfertilized *Heteropogon* oversown with *S. humilis* produced 148 and 93 kg LWG/ha/yr respectively (*86*). At another site, grazing at 0.6/ha produced 85 and 63 kg/ha/yr/LWG on treatments receiving superphosphate or not (*61*). In north Queensland, steers grazing at 0.4 ha produced 52 and 30 kg/ha/yr on *S. humilis* pastures with or without superphos-

phate respectively (*83*). At another site, superphosphate at nil, 126 or 377 kg/ha/yr gave average weaned calf weights per cow mated of 116, 144 and 165 kg respectively. Droughtmaster cows were grazed at 0.4 and 0.8/ha but stocking rate effects were not significant (*87*). These studies were each based on from 3 to 7 years data, and indicate a range of responses whose profitability has varied with economic conditions. Much depends on the residual fertilizer responses and the level of maintenance fertilizer required.

Improved Moisture Supply

Irrigation is used to assist whole milk production in the tropics, but will be rarely applied to natural grazing lands, since the returns from irrigated cropping are superior. The forage supply in cropping districts is improved by irrigation, since the banks between flooded bays and tail-race areas often grow forage, and the amount of crop residues is increased. Simple water-spreading schemes (e.g. *88*), in which run-off water from the steeper slopes is diverted from creeks and gullies by low earth banks and spread over gently sloping natural grasslands with higher infiltration capacity, are less capital-intensive than conventional irrigation schemes. Both continuity and amount of green forage supply are enhanced.

Removal of trees improves the moisture supply to grasses, and the run-off characteristics of watershed grasslands are modified by plant cover, which in turn is influenced by stocking rate and burning practice.

Control of Stocking Rate

The biomass of the ruminant animals on the pasture is the first determinant of efficiency of pasture use, and may be manipulated to optimize product output. On some grazing lands, animal density is self-regulating, and is determined by the various environmental (including nutritional) stresses which affect reproductive efficiency; in many production systems stocking rate is more susceptible to managerial decision. The data of stocking rate experiments indicate best fit to a simple, linear, negative relationship between LWG per head and increasing stocking rate (*89*). This leads to a quadratic relationship between LWG per unit area and stocking rate, in which the stocking rate giving maximum biological output per unit area occurs when individual LWG is just one half the theoretical maximum; in practice the long-term economic optimum stocking rate may be as low as 40 percent of this figure.

The optimum stocking rate is determined first by the amount of forage grown, which is increased according to the inputs such as fertilizer (*90*), legume overseeding (*86*) or tree-clearing (*34*), which are applied. It is modified by accessibility of forage, strong gradients being associated with distance from settlement or water, nutritive value, which dictates the level of selectivity needed, the dynamics of botanical composition in relation to grazing pressure, variability in forage supply, and the type of animal product and its sensitivity to nutritional stress. There is considerable scope for increasing stocking rate in more than half of the tropical humid and subhumid grazing lands, provided extra inputs are made.

Continuity of Forage Supply and Supplementation

Animal stress may be minimized by various strategies which improve continuity of forage supply (*91*). Synchronization of reproductive demands and of animal purchase and sale with the available forage supply reduces stress. Improved husbandry practices, involving the control of mating and weaning, must be concurrent with pasture improvement. Conservation of natural pasture surpluses is rarely practised in the tropics, since there are many inefficiencies inherent in this feeding system and the nutritive value of the conserved product is low; crop residues or cultivated forages provide more scope for hay or silage making. Standing surplus forage may be utilized more completely if burning is controlled (*92*) and if the nutrient balance of the forage is rectified by supplementary feeding. Responses to protein or non-protein nitrogen commonly occur in the tropics (*93*); this effect may also be achieved by feeding special purpose legume areas. Energy feeding is often substitutionary rather than supplementary (*94*). Mineral deficiencies in the diet need to be locally identified, and responses to phosphorus (*95*), sulphur (*96*), cobalt (*97*) and copper (*98*) have been reported from ruminants fed tropical pastures.

POTENTIAL FOR RUMINANT PRODUCTION

Examples of Increased Animal Output

Examples have been given earlier in the paper of the scale of increase in ruminant production due to clearing forest and to fertilizing grazing lands overseeded with legumes. The simplest and lowest cost plan is the addition of pasture legumes to natural grazing. In central Queensland (*61*) sowing *S. humilis* in *Heteropogon* pastures on a granitic soil increased LWG from 35 to 64 kg/ha; strip sowing 0.25 of the area gave the same increase as sowing the whole area. On a prairie soil (*86*) production was raised from 25 to 93 kg/ha; on another granitic soil (*99*) the comparison was 44 and 122 kg/ha. At an adjacent site (*34*) the maximum production from cleared woodland dominated by *Heteropogon* was 46 kg/ha, compared with 115 kg/ha from fertilized grassland oversown with *M. atropurpureum* cv. Siratro. A similar comparison further to the south (*48*) gave a positive response of 28 kg/ha.

The establishment of special-purpose legume dominant pastures grazed in conjunction with natural grasslands is an alternative strategy to overseeding the whole grazing area; the benefits of a small, concentrated input are then extended to a much larger area through the correction of protein deficiency and improved continuity of forage supply. Haggar *et al.* (*47*) recommended the grazing of 1.8 ha of *Hyparrhenia-Andropogon* savannah in northern Nigeria with 0.5 ha *S. guyanensis* per head, and equated the effect of the legume to feeding 0.8 kg/head/day cotton seed during the long dry season. In the Northern Territory of Australia, output from cattle grazing *Themeda*, *Sorghum*, *Chrysopogon* and *Sehima* grassland at low stocking rates increased from 7 kg/ha to 11 kg/ha if access to 0.2 ha *S. humilis* was given (*100*). At an adjacent site (*101*), level of access to supplementary grazing of *S. humilis* varied LWG of weaner steers linearly from 56 to 293 kg/hd over a period of 630 days. In Fiji (*102*) steers grazing *Dichanthium caricosum* pastures at 1.5 ha gave 110, 170 and 270 kg/ha/yr if 0, 10 and 20 percent respectively of the pasture area was devoted to fertilized *Leucaena latisiligua*. In southern Queensland (*91*) steers grazing *Heteropogon-Bothriochloa* grassland at 0.4/ha gained 34 and 63 kg/ha/yr if nil or 17 percent respectively of the area grew *Medicago sativa* which was both grazed and conserved for cool season feeding.

Further increases result from the replacement of the natural grasslands with cultivated species. The examples quoted are drawn from experiments, and increases in farm production from legume introduction are expected to be substantially less. However, in view of the almost universal protein deficiency evident in the tropics, a factor of increase of, say, 1.6 should be attainable from this input alone. An increase of this magnitude would be partly dependent upon increased cattle numbers; this, however is a most attractive form of increasing capital in the developing world. The combined effects of thinning woodland, overseeding *M. atropurpureum* cv. Siratro, fertilizing with molybdenized superphosphate, and raising stocking rate increased LWG from 35 to 128 kg/ha/yr in one central Queensland study (*34*). In other central Queensland studies the combined influences of overseeding *S. humilis*, fertilizing and raising stocking rate increased LWG from 35 to 85 kg/ha/yr (*61*), or from 25 to 148 kg/ha/yr (*86*). In this region this form of intensification on grasslands currently grazed may increase production by a factor of from 2 to 7.

Projections of Animal Output

Recent trends provide a guide to further possibilities, and Table 4 shows the computed relative annual increase in ruminant population and output in the humid and subhumid tropics for the selected periods 1961-65 to 1969-73. Animal census and production data are unreliable in many countries from which FAO made their estimates, and the varying use of animals for draft, meat, milk, or other purposes limits the utility of the figures in Table 4.

The relative increase in animal density is partly a negative function of the degree of natural resource exploitation; one expects less increase in India or Java than in Colombia. The mean cattle figure of 2.0 percent for the regions compares satisfactorily with the world average of 1.7 percent. High values occur for South America, mainly due to the Brazilian estimates, and for Central America. The Sahelian and Ethiopian droughts in the latter part of the period mainly affected the semi-arid zone figures for Africa, but influenced the subhumid areas also. The increase in Asian buffalo density of 0.8

Table 4 — Relative annual increase in ruminant population and output in the humid and subhumid tropics, 1961-65 to 1969-73

Region	Cattle	Buffaloes	Sheep	Goats	Meat	Milk
			Percent			
Africa	1.7	—	-0.8	0.4	0.7	2.5
Central America	2.8	—	-0.5	0.8	3.1	3.7
South America	4.4	—	2.3	1.4	3.7	3.4
Asia	0.6	0.8	0.2	1.4	1.1	1.5
Oceania	2.1	—	—	—	1.8	-2.9
Subtotal	2.0	0.8	0.6	1.0	2.4	2.2
World	1.7	1.2	0.2	0.2	2.4	1.6

Source: (*4*)

percent incorporates decreases in Thailand and Indonesia. The smaller ruminants increased less than cattle, despite their shorter gestation period. The high figure for sheep increases in South America is due to Brazilian and Peruvian estimates.

Meat output (Table 4) from ruminants (beef, veal, lamb and mutton) in the humid and subhumid tropics increased relatively at 2.4 percent per annum. This was equal to the world average, in which the poorer performance of the arid zone was counterbalanced by Northern American and European production increases. A small increase in mutton and lamb production was reported from Brazil, India and South Africa, but almost all the increase in ruminant meat output is attributable to cattle. The highest rates of relative increase, 3.7 and 3.1 percent for South and Central America respectively, are mainly due to estimates from Brazil, Venezuela, Panama, Nicaragua, Costa Rica, and Guatemala.

The relative increase in milk production was greater (2.2 percent) for the humid and subhumid tropics than for the world (1.6 percent); this was due to superior increases in Central and South America, associated with cow (rather than sheep or goat milk) production in Peru, Ecuador, Venezuela, Costa Rica, Honduras, Guatemala, Dominican Republic, and Mexico. In Africa, Nigerian milk production rose relatively rapidly; in Asia increased milk production was attributable to the buffalo in India, and to dairy cattle in Sri Lanka. A shift in milk production from sub-tropical pastures in Queensland to temperate pastures farther south caused the negative figure for Oceania.

The factor of change to the year 2000 has been calculated from Table 4. If the same rate annual change which operated from 1961-65 to 1969-73 continued for a further 29 years, ruminant population would increase by a factor of 1.8, 1.3, 1.2, and 1.3 respectively for cattle, buffaloes, sheep and goats grazing in the humid and subhumid tropics (Table 5); meat and milk production would double. Total world meat production doubled between 1950 and 1970, and these increases are believed to be feasible in terms of available biological resources. However, these figures do not meet the projected annual increases in demand for meat and milk, which are estimated as 4.2 and 4.6 percent respectively, by the F.A.O. Indicative World Plan. These give rise to factors of increase of 3.3 and 3.7 required by the year 2000. Can enough of the world's environmental and human resources be allocated to achieve these targets?

Key Assumptions in Estimating Potential

Estimation of the ceiling biological yield for ruminant output from the humid and subhumid tropical grasslands is not very meaningful when forecasting developments to the year 2000. The character and size of the existing ruminant populations, competition for environmental and human resources, and institutional arrangements create a framework of constraints which preclude the adoption of some pathways to increased production. It is more relevant to discuss strategies directed to realizing biological potential which are likely to be feasible within this framework of constraints. This discussion is also restricted to the ruminant feed base; gains from improved animal health and genetic performance are additional.

The following assumptions are made:

Table 5 — Factors of projected change in ruminant population and output in the humid and subhumid tropics, 1971 to 2000.

Region	Cattle	Buffaloes	Sheep	Goats	Meat	Milk
Africa	1.6	—	0.8	1.1	1.3	2.0
Central America	2.2	—	0.9	1.2	2.5	2.9
South America	3.4	—	1.9	1.5	3.0	2.6
Asia	1.2	1.3	1.1	1.5	1.4	1.5
Oceania	1.8	—	—	—	1.7	0.4
Subtotal	1.8	1.3	1.2	1.3	2.1	1.9
World	1.6	1.4	1.0	1.1	2.1	2.0

Source: Calculated from Table 4

1. The level of economic demand for animal protein primarily determines the rate of development. Human dietary deficiencies in some regions will not inevitably lead to increased animal production. For example, pasture sowings in Queensland (*54*) decreased from 0.29 M ha in 1973 to 0.13 M ha in 1974, due primarily to reduced export beef demand. The extent of governmental initiatives in improving roads may determine the extent of the area in which it is profitable to overseed *S. humilis* (*103*).

2. Feedlot operations in which confined animals are fed grain and intensively produced fodders can only be considered a disastrous program for the tropics. Grain fed to ruminants is inefficient in meeting human food needs, in use of energy, and in use of economic resources. The trade policies of all nations adopting this form of production, with rigid embargoes or quota restrictions on imports of pasture-fed beef, provide the clearest comment on its intrinsic inefficiency. The diversion of unused byproducts from agricultural processing to cattle production is less objectionable, but represents a high-cost option.

3. Land suitable for the production of crops for human food, fiber or for high-value industrial products should not be allocated to intensive pasture production. In some circumstances, short-term pastures may be necessary to maintain crop production, or companion cropping of forage legumes may promote more efficient use and cycling of crop residues. The current net rate of expansion of agricultural land — 2.7 M ha/yr in Latin America, Africa, Asia and Oceania (*104*) — of urban areas, and the competing needs of urban societies for recreation and watershed areas reduce the land available for grazing. However, in most tropical regions this growth can be more than compensated to the year 2000 by the more intensive animal use of forest and open woodland areas.

4. Under-employment of rural labor will continue in most tropical countries. The impact of current population control programs may slow down the numbers of people entering the work force by 2000, but a real scarcity of rural labor will be unusual.

5. Low energy-cost solutions should be sought. This implies low priority to strategies involving fertilizer-nitrogen, intensive mechanization, and some forms of irrigation.

6. With significant exceptions, grazing lands in the humid and subhumid tropics are not overstocked. Grazing pressure is too high in abnormally dry years, but usually reserve pasture is not consumed, due to nutrient imbalances or inaccessibility. This contrasts with the situation in many semi-arid and arid regions, where the preservation of the ruminant feed base requires reduced animal numbers in many areas.

7. The climates of the humid and subhumid zones are all suited to the introduction of sown pasture legumes, although production benefits are inevitably less in the drier zones. For example, nitrogen accretion from *S. humilis* pastures is very much greater in areas with 800 mm annual rainfall than in 600 mm zones.

8. The reproductive efficiency, survival and rate of fattening of most local ruminants are increased by improved pasture quality and availability. Some mistaken applications of data comparing the efficiencies of response of various breeds and species to high levels of concentrate feeding have occurred (*104*). The tropical field

A Zebu cattle roundup in Colombia. With few exceptions, grazing lands in the humid and subhumid tropics are not overstocked. *World Bank photo.*

situation where responses are sought to the correction of protein and mineral deficiencies and to improved continuity of pasture supply is quite different. Lower individual rates of animal gain from small cattle may well give equivalent outputs per unit area at equivalent biomass per unit area of large cattle. For example, small yellow Asian cattle grazing legume based pastures in central Laos average 0.3 kg LWG hd/dy year-round, at 3 to 5 beasts/ha (*105*) and calving rates in excess of 90 percent are claimed; Balinese cattle in west Bali can yield 600 kg LWG ha/yr. The quality, amount, and continuity of the forage supply is the primary factor limiting animal output in the tropics, and the existing ruminant population is responsive to its improvement.

9. The strategies most likely to be successfully adopted are (i) increasing pasture supply by thinning woodland and forest and controlling regrowth with judicious use of fire and stocking, (ii) increasing pasture accessibility by provision of stock water, (iii) increasing pasture quality and growth by overseeding legumes or using special purpose legume stands in conjunction with natural pasture; non-nitrogenous fertilizers will be required in many areas, (iv) correcting nutrient deficiencies in the pasture diet by mineral (including nitrogen) supplementation, (v) replacing natural grasslands with planted grasses and legumes.

From the examples quoted, it appears that the biological potential of these five strategies is sufficient to give annual increases of 4.2 percent for meat and 4.6 percent for milk production (F.A.O. Indicative World Plan) in the humid and subhumid tropical sector. However, this would require a drastic re-allocation of resources to ruminant production, and a concomitant increase in economic demand to bring this about.

Regional Potentials for Ruminant Production

Resource surveys in the tropics have been conducted on different bases for various purposes, and in view also of their limited coverage, it is difficult to integrate these findings to provide a world coverage. As technology changes, land use potential is viewed in radically different categories, and the negative findings of some early surveys have been swept aside by the actual march of development.

In Northern Australia, the area north of the tropic suitable for colonization by *S. humilis* was estimated by Begg (*106*) as 39 M ha. This was based on a minimum growing season of 15 wk, and excluded areas subject to waterlogging, saline soils, heavy cracking-clay soils, and hilly country with rocky outcrops and skeletal soils. Davies and Eyles (*107*), taking the 510 mm isohyet as the limit of development, suggested optimistically that 105 M ha of Australia north of lat. 30°S was suitable for pasture improvement, giving a reserve capacity of about 52 M additional cattle. This area estimate has been revised by Hutton (*108*) to 40.4 M ha suitable for legume establishment, with a reserve cattle potential of about 30 M additional cattle in the next 50 years. Population projections indicate that a considerable food export from Australia is expected to continue (*109*).

In Asia the intensification of ruminant production in well-developed cropping areas depends upon the more efficient use of crop residues and waste lands. This applies to many districts of central Java, central Thailand, Bangladesh and India. However, there are vast areas of watershed grasslands, savannah woodland and forest awaiting development in Burma, northern and north-eastern Thailand, Laos, Vietnam, Malaysia, Indonesia and the Philippines. Whiteman (*110*) has identified 4.1 M ha of land in Sumatra, South Kalimantan, Sulawesi and Nusa Tenggara which is particularly suited to pasture improvement. Javier (*111*) estimates the potential grazing land of the Philippines as 2.1 M ha. In the southeast Asian zone, 2.5 M ha of coconut plantings provide opportunity for further diversification to ruminant production (*18*). African savannahs also provide an immense potential for increased ruminant production. For example, Adebgola (*112*) estimates the grassland resources of Nigeria as 56 M ha, which provide scope for increasing the current meat off-take of 0.15 MT from 11 M cattle. Pratt *et al.* (*113*) have delineated savannah areas in East Africa suitable for improvement.

By far the greatest ruminant potential lies in Latin America. Greater areas of land receiving rain in excess of 1,000 mm are available than in the tropical regions of other continents, and there are savannahs of gentle relief in which development inputs to increase cattle production can occur more cheaply than elsewhere. The low human population density in these areas minimizes competition with ruminant production. The cerrados and campos of Brazil, the sabanas of Venezuela, Guyana and Surinam, the llanos of Colombia and the beni of Bolivia provide a diversity of resources capable of intensification. Grof (*114*) estimates there are about 250 M ha of underutilized savannah in Brazil, Venezuela, and Colombia capable of ready improvement. de Miranda (*115*) quotes recent work in Rio Grande Do Sul where under experimental conditions, the calf crop has increased from 50 to 75 percent, slaughter age has reduced from 4.5 to 2.5 years, extraction rate has increased from 12.5 to 26 percent, and beef output has increased from 45 to 113 kg/ha. Paladines *et al.* (*116*) reported that the replacement of a natural pasture in Colombia with *Melinis minutiflora* increased LWG from 8 kg/ha to 64 kg/ha/yr. In Venezuela, de Jongh *et al.* (*117*) have compared models of ruminant production in which different input strategies were contrasted; a program of brush control on natural grazing might lead to an increase in the national cattle herd from 7 M to 10.5 M by the year 2000.

These brief examples do not provide a collated estimate for the whole of the humid and subhumid tropics, but indicate favorable opportunities in all continents to meet expected economic demands for growth of ruminant production. The resource base has been summarized in Tables 1 and 2.

Research Inputs Needed

It is sometimes argued that the slow progress of development in the tropics is due to institutional constraints, or to the acceptance and approval farmers give to traditional ways, which inhibit the adoption of innovations. A further view which has more force is that research has not generated the innovations that justify the allocation of further resources to ruminant production. Farmers are rightly skeptical of technology transferred laterally from other regions and other societies, and many of the innovations offered are inappropriate to their goals and to their farming systems.

In recent decades, the growth of education and the establishment of local universities and experiment stations have been substantial in many tropical regions. The research output which has been incorporated in farming systems is small. Expatriate-based research has of-

ten concentrated on strategies not pertinent to local needs, for example, capital-intensive systems; indigenous research has still been evolving its standards. In the field of ruminant production there has been inordinate attention given to problems of animal health and of animal breeding, and insufficient attention to the feed base, the deficiencies of which created some of the health problems and seriously limited responses to improved health practice and genetic base. Resources allocated to agricultural research have been self-regenerating in many societies. There are no intrinsic reasons why more successful research which is catalytic in its effects cannot take place in fields associated with tropical ruminant production, and this paper has referred to examples of real advances.

Many successes in other fields are associated with the establishment of international agricultural research institutes, such as CIMMYT and IRRI. The question arises as to whether resources should be sought for the establishment of an International Tropical Grassland Research Institute. Such an institute could function as a "center of excellence," maintaining high standards of research and initiating long-range programs directed to reducing the limitations to ruminant production from tropical grassland. As part of its program, it could maintain an international gene pool of selected pasture species, especially legumes; this would prevent the dissipation of genetic resources which may follow the destruction of natural vegetation in centers of specific diversity and protection, and would provide access for research workers in pasture plant improvement from all tropical regions. It could have an important role in training junior scientists and in providing liaison between tropical grassland scientists through information services, workshops and conferences. The location of such an institute would pose many problems. The greatest concentration of tropical grassland scientists occurs in northern Australia, but it may be inappropriate for an international tropical research center to be located in a region with a high-wage economy; a Latin American center might be more complementary. However, in view of the existing contribution of CIAT, the alternative would be to concentrate in Southeast Asia on the development of *Imperata* grasslands.

Any well-balanced research program will have different types of objectives, with differing time scales for their achievement. In each general region the fundamental attacks on the limitations to the efficiency of ruminant production discussed earlier need to be supported by adaptive research in farming districts. While it is tempting in the short-term to rely on contract, expatriate research, the long view dictates the need for both the local formulation of research problems as understood from local production systems, and a traffic of ideas and experiences between the local research worker, extension adviser and farmer in the testing of innovations.

Tropical pasture science is a young discipline, and there are so many sectors where scientific research is yielding early dividends that there is a special difficulty in allocating priorities; these will also have differing importance in various regions. The following priorities are recognized:

1. Tropical pasture legume selection and breeding. Although there is a wide spectrum of cultivars available, there are deficiencies for the boundaries of the subhumid zone, and for the frostier subtropics. Many perennial legumes with good seed-production characteristics are not sufficiently tolerant of heavy grazing. A better understanding of the adaptive processes by which plants are successful in heavily grazed situations and of the environmental factors which condition plant response is needed (*118*). Studies of the manner in which grazing affects the various pathways of plant persistence can lead both to management recommendations and to the definition of plant selection objectives. The need for local research is underlined by the local character of disease and pest attacks; for example, varieties of *S. guyanensis* successfully introduced to Australia fall victim to stem-borer and to various pathogens in Colombia (*114*). The development of more efficient symbiosis with more incursive lines of Rhizobium would increase nitrogen-fixation. Although individual animal output is usually higher from legumes than grasses, tropical legumes are inferior to temperate species in this respect; low forage bulk density is one factor involved (*119*). More research is needed to develop legumes suited to the improvement of swamp grassland.

2. Legume fertilizer requirements. A further aspect of legume selection is the need for plants efficient in the extraction of nutrients at low levels of supply and tolerant of mineral excesses such as aluminium, manganese and salinity.

The definition of local fertilizer requirements for successful legume growth and nitrogen fixation and the development of diagnostic techniques with wide applicability are needed, especially for the assessment of maintenance fertilizer needs.

3. In intensively farmed areas, more attention might be given to the utilization of crop residues by ruminants, the undersowing of fodder legumes in other crops, and the development of animal feeding systems which are compatible with maximum crop production.

4. More studies of the relationships between grazing pressure, pasture dynamics, and animal output are needed. The determination of optimum stocking rates on different grassland types at differing levels of inputs and the recognition of species indicative of over-grazing will help to formulate management recommendations.

5. Problem tree and shrub species not readily controlled by currently available arboricides require study.

6. Better inventories of natural grazing land resources will assist development planning and the orientation of research work.

Educational and Other Inputs Needed

The training of grassland research and extension workers depends first upon the upgrading of local universities; this has occurred in some tropical countries. "Third country" scholarships, in which students are trained in a neighboring country with regional affinities, should be offered to students whose own country's facilities are inadequate for good first-degree training. Many students who earn their first degree in temperate zone countries with capital-intensive agricultural systems are socially dislocated, and are always removed from their own farmers' problems. On the other hand, overseas post-graduate training of mature students is a necessary part of the upgrading process. The provision of short international training courses and workshops exposes grassland workers to contemporary concepts and techniques and develops professional contacts; they are also a useful aid in the selection of scientists for more intensive training.

The training of technicians and of farmers is best achieved at the local level in the context of local problems. The provision of grassland extension services demands the cooperation of many different disciplines, and has often foundered on the narrow base of training received by veterinarians. Farmer training centers, in which short residential courses are given, are increasingly being developed to supplement farm demonstrations, grassland group discussion programs, and information bulletins.

The question of developing incentives for producers to increase ruminant production is outside the scope of this paper. The vast biological potential of the humid and subhumid grazing lands depends for its realization on the human resources of the local farmers, and their production incentives. These are conditioned by the available technology and the capital inputs needed to implement it, transport and marketing structures, and institutional arrangements which give adequate priority to these developments.

SUMMARY

The grazing lands of the humid and subhumid tropics feed about 40 percent of the world's ruminant animals, which contribute about 15, 11 and 12 percent respectively of the world's beef, mutton and milk. These grazing lands comprise swamp grasslands, derived watershed grasslands, savannah woodlands, grazing lands associated with cropping and settlement, and montane grasslands.

Preferred strategies for increasing ruminant output are (i) thinning woodlands, (ii) increasing pasture accessibility by provision of stock water, (iii) overseeding and fertilizing pasture legumes, (iv) mineral (including nitrogen) supplementation of grazing animals and (v) replacing natural grasslands with cultivated pastures. The biological potential of these strategies applied to the existing resource base is considered theoretically sufficient to give annual demand increases of 4.2 percent for meat and 4.6 percent for milk production through 1985 (F.A.O. Indicative World Plan), especially in Latin America, but these targets would require great reallocation of resources to ruminant production. Current annual increases in the humid and subhumid tropics are estimated as 2.4 percent and 2.2 percent for meat and milk respectively.

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POTENTIAL OF TROPICAL ZONE CULTIVATED FORAGES

for Ruminant Animal Production

LOY V. CROWDER[1]

Properly managed cultivated grasses and legumes in the tropical zones (*1*) have the potential to improve forage quality and increase herbage yields several-fold over that of native and naturalized grazing lands. Their use in pastures would lead to dramatic improvement in production per animal and per unit of land area. Improved selections and cultivars, however, are used in less than five percent of sown pastures in most tropical regions.

Grasses are the predominant vegetative plants of most sown pastures and native and naturalized grazing lands. Without intensive management, their growth follows the seasonal moisture regime so that grazing animals show a stop-and-grow pattern of liveweight gain.

Legumes usually do not contribute significantly to the herbage in most grazing lands. Cultivated types, however, provide a tremendous potential in improving forage quality, increasing animal forage intake, maintaining a high level of digestibility, extending the grazing period, and adding nitrogen to the soil-plant-animal system.

During the dry season, forage is usually scarce, and whatever the animals can find is generally a low quality and does not provide sufficient digestible energy and crude protein for animal maintenance. To avoid this condition, improved pastures need to be integrated into year-round feeding programs. Research of the soil-plant-animal complex needs to be extended over a broader spectrum of tropical environments and practical technology should be made available to livestock producers in forms that they can understand and use.

Species with Potential as Cultivated Forages

A high proportion of the recognized 10,000 grass species (*2*) contributes to natural grazing, but only 40 were listed in 1956 (*3*) as comprising 99 percent of the earth's sown grass pastures. At least 14 species occurred predominantly in the tropical and subtropical zones. The list of warm season grasses can now be expanded as indicated in Table 1. In recent years more attention has been given to collecting, evaluating, and improving grasses and legumes as pasture and forage crops. Thus, the number of cultivated types should continue to increase in the future.

Fewer legume species are cultivated than grass species, even though the legume family is larger. In general, legumes are less likely to be a predominant component of naturalized grazing lands and usually contribute less herbage for grazing. They are more difficult to establish, grow more slowly as seedlings, are less competitive in mixtures, require an effective *Rhizobium* for inoculation and growth, and are more difficult to maintain. Until recent years they attracted less attention than their companion grass species.

Species other than those listed in Table 1 should be recognized, since they also contribute to grazing or have potential as cultivated types. Grasses in these categories include: (a) at the lower elevations in the tropics and subtropics — *Brachiaria brizantha* (Hochst.) Stapf (Palisade) (*4*), *Digitaria pentzii* Stent., *D. smutzii* Stent., *Eragrostis curvula* Nees (Weeping love grass), *Eriochloa polystachya* H.B.K. (German grass), *Panicum maximum* var. *trichloglume* Eyles (green panic), *Paspalum commersonii* Lam. (Scrobic), *P. dilatatum* (Poir) (Dallas), *P. plicatulum* Michx. (Brown-seeded paspalum), *Tripsacum laxum* Nash (Guatemala), *Urochloa mosambicensis* (Hack.) Dandy (Sabi); (b) at the higher elevations — *Agrostis gigantea* Roth. (Red top), *Avena sativa* L. (Oat), *Bromus catharticus* Vahl (Rescue), *Dactylis glomerata* L. (Orchard, cocksfoot), *Festuca arundinacea* Schreb. (Tall fescue), *F. pratensis* Huds. (Meadow fescue), *Lolium multiflorum* Lam. (Italian ryegrass), *L. perenne* L. (Perennial ryegrass),

[1] Loy V. Crowder is Professor, Dept. of Plant Breeding and Biometry, Cornell University, Ithaca, NY 14853

Table 1. Principal cultivated grasses and legumes in the tropics and subtropics.

Botanical Name	Common name	Native regions
Grasses		
1. **Andropogon gayanus* Kunth.	Gamba	Tropical Africa
2. *Axonopus compressus* (Sw.) Beauv.	Carpet	Tropical & Subtropical America
3. **Axonopus scoparius* (Flugge) Hitchc.	Imperial	Central & South America
4. *Brachiaria decumbens* Stapf	Signal	Tropical Africa
5. *Brachiaria mutica* (Forsk.) Stapf	Para	Tropical Africa & Tropical South America
6. *Brachiaria ruziziensis* Germain et Evrard	Ruzigrass, Congo	Tropical Africa
7. **Cenchrus ciliaris* L.	Buffel	Africa, India, Indonesia
8. **Chloris gayana* Kunth.	Rhodes	Africa
9. **Cynodon dactylon* (L.) Pers.	Bermuda, Couch	Tropics & Subtropics
10. **Cynodon nlemfuensis* Vander.	Giant Cynodon	Tropical Africa
11. *Dichanthium aristatum* (Poir.) C.E. Hubb.	Angleton	E. Africa, India
12. *Digitaria decumbens* Stent.	Pangola	South Africa
13. *Hyparrhenia rufa* (Nees) Stapf	Jaragua	Tropical Africa
14. **Melinis minutiflora* Beauv.	Molassis	Tropical Africa
15. **Panicum antidotale* Retz.	Blue panic	S.E. Asia
16. **Panicum coloratum* L.	Kleingrass	East Africa
17. **Panicum maximum* Jacq.	Guinea	Tropical & Subtropical Africa
18. **Paspalum notatum* Flugge	Bahia	Tropical & Subtropical Africa
19. *Pennisetum clandestinum* Hochst.	Kikuyu	E. Central Africa
20. *Pennisetum pedicellatum* Trin.	Kyasuwa	Tropical Africa, India
21. **Pennisetum purpureum* Schum.	Elephant, Napier	Tropical Africa
22. **Saccharum officinarum* L.	Sugarcane	India
23. **Setaria anceps* Stapf ex Massey	Setaria	Africa
24. **Sorghum almum* Parodi	Columbus	South America
25. **Sorghum sudanense* (Piper) Stapf	Sudan	Tropical Africa
Legumes		
1. **Cajanus cajun* (L.) Mills.	Pigeon pea	Africa, Asia
2. *Calopogonium mucunoides* Desv.	Calopo	South America
3. **Centrosema pubescens* Benth.	Centro	South America
4. **Desmodium intortum* Mill.	Greenleaf	Tropical America
5. **Desmodium uncinatum* (Jacq.) DC.	Silverleaf	Tropical America
6. **Glycine wightii* (R.Grah. ex Wight & Arn.) Verdc.	Glycine	Africa
7. **Lablab purpureus* (L.) Sweet	Hyacinth bean	Africa, Asia
8. **Leucaena leucocephala* (C. Lam.) de Wit	Lead tree, Ipilipil	Tropical America
9. **Lotononis bainesii* Baker	Lotononis	Africa
10. **Macroptilium atropurpureum*	Siratro	Tropical America
11. **Medicago sativa* L.	Alfalfa, Lucerne	Central Asia, S. Europe
12. *Pueraria phaseoloides* (Roxb.) Benth.	Puero, Kudzu	East Asia
13. **Stylosanthes guianensis* (Aubl.) S.W.	Stylo	Tropical America
14. **Stylosanthes humilis* H.B.K.	Townsville stylo	South America

*Improvement through selection or breeding.

and *Phalaris tuberosa* L. var. *stenoptera* (Hack.) Hitchc. (Harding). Legumes in these categories include: (a) at the lower elevations — *Aeschynomene americana* L. (Joint-vetch), *Centrosema virginanum* (Benth.), *Clitoria ternatia* (L.) Dne. (Butterfly, Kordofan), *Desmodium canum* (Gmel.) Schinz. et Tell (Kaimi clover), *Indigofera spicata* Forsk (Trailing indigo), *Macroptilium lathyroides* (L.) Urb. (Phasey bean), *Macrotyloma axillare* (E. Mey) Verdc., *M. uniflorum* (Lam.) Verdc. (Horsegrain), *Stylosanthes hamata* (L.) Taub. (Caribbean stylo), and *Vigna luteola* (Jacq.) Benth.; (b) at the higher elevations — *Medicago hispida* Gaertn. (Bur clover), *M. truncatula* Gaertn. (Barrel medic), *Trifolium pratense* L. (Red clover), *T. repens* L. (White clover), and *T. semipilosum* Fresen. (Kenya white clover).

Value of ecotypes — In their native regions, a majority of the grass and legume species flourish as a part of the indigenous flora. In some instances they occupy special climatic niches and are recognized as ecotypes or agrotypes. Often a local name is conferred which, in a sense, connotes an improved or superior type developed under the conditions of natural selection. For example, pasture agronomists (agrostologists) in Kenya surveyed and studied indigenous grasses and legumes, identifying ecotypes among species such as *Cenchrus ciliaris*, *Chlorus gayana*, *Cynodon dactylon*, *Panicum maximum*, *Pennisetum clandestinum*, *P. purpureum*, *Setaria anceps* (syn. *S. sphacelata*), *Glycine wightii* (syn. *G. javanica* L.), *Lablab purpureus* (syn. *Dolichos lablab* L.) and *Trifolium semipilosoum* (*5*). Selections have been used in sown pastures in Kenya. Many of the superior genotypes were moved to different locations in the tropics and subtropics and identified as cultivars, e.g. Nandi Setaria, Masaba Rhodes grass, Makueni guinea grass, Kabete white clover (*6*).

In most regions, superior types of species were not locally recognized as having potential in their native habitat but simply grew as a part of the natural vegetation. Plant explorers harvested seeds of genotypes which happened to be more mature during the occasional visit to a given site. The seeds were returned to the sponsoring country and evaluated in plant introduction gardens for general adaptation and potential as pasture or forage types. Those with promise were tested under different ecological conditions by using various agronomic practices and grazing animals. Emerging as superior types, they were named as cultivars and registered by the proper governmental agency. This procedure has been followed by the CSIRO (Commonwealth Scientific and Industrial Research Orgazation) of Australia since 1947 (*7*, *8*). For example, Greenleaf (*Desmodium intortum*) is a mixture of three introductions from El Salvador and Guatemala and Silverleaf (*D. uncinatum*) represents a single introduction from Brazil (*9*). Both have performed well and made significant contributions to pasture development and production in regions of adaption in Australia. Seeds produced commercially in Australia have been shipped to all parts of the tropics, including the countries from which the introductions came and where common genotypes of both cultivars still exist in the native vegetation.

Several cultivated species came to the attention of cattlemen or pasture agronomists as propitious introductions. Under favorable conditions, seeds scattered and became an important component of the natural vegetation. Such was the case of Townsville stylo in northeastern Queensland, Australia (*10*). This legume was found to be widely spread around Townsville in the 1920's where it was relished by cattle. It is thought that seeds arrived by ships from Brazil in the early 20th century, and the environment was suitable for natural selection and development of an ecotypic population. Townsville stylo is an annual which produces 2.0 to 3.0 tons per hectare of dry herbage as well as a heavy seed crop during the rainy season in northeast Queensland and Northern Territory. It is lightly grazed during this period and then utilized as foggage (standing hay) in the dry season. This one legume aided considerably in the transformation of natural grazing lands, where one animal roamed over 15 to 20 hectares of poor quality native grass to pastures that now support one animal unit on slightly more than one hectare. Townsville stylo seeds are produced commercially and several new cultivars have been selected among variants occurring in the diverse population (*9*).

Grass and legume collections are sometimes introduced only to remain relatively unknown in a plant nursery for many years. Pangola grass was brought from the Transvaal region of South Africa to Florida in 1936, where it survived in an introduction garden for about 20 years (*11*).

A visitor then noted its vigorous growth characteristic, took stolons to a nearby experimental station and distributed materials for local grazing. In new environments, others recognized its potential as a pasture crop and within a few years, vegetative material (being a sterile hybrid) was spread over the global tropics. In fact, during the 1950's and 1960's this species became more widely distributed than any other in a given period of time. Unfortunately, some very good pastures with species such as guinea grass were destroyed to transplant Pangola. It is widely adapted and highly productive under intensive management, but plants of Pangola pastures represent a single genotype, thereby creating a serious vulnerability to disease and insect attack.

Cultivars from breeding programs — A vast majority of grass and legume species introductions are never selected for commercial seed production. They may be utilized, however, as a source of germplasm for recombination of types in pasture and forage crop breeding programs. Of the principal cultivated species listed in Table 1, only a few were derived for application of breeding procedures other than selection of ecotypes or mass selection among direct introductions.Those developed in breeding programs include: Cancreep alfalfa (*9*), Coastal and Coastcross 1 Bermuda grasses (*12*, *13*), Krish sorghum (*14*), Nandi Setaria (*6*), Siratro (*15*), Tifton sudan and Tifhi No. 1 Bahia grasses (*16*). Other species being studied in breeding programs include *Cynodon* and *Pennisetum* F_1 hybrids (*P. purpureum* x *P. typhoides* in Nigeria (*17*); centro (interspecific hybridization), *Desmodium* and stylo in Colombia (*18*); *Digitaria* (interspecific hybridization), limpograss (*19*), and *Panicum maximum* (crosses of sexual and apomictic genotypes, personal communication) in Florida; guinea grass, Klein grass, Rhodes grass, ruzigrass and *Setaria* in Kenya (*20*); guinea grass in Ivory Coast (*21*); *Cenchrus*, centro, *Digitaria*, *Desmodium* and *Sorghum* (interspecific hybridizations), *Leucaena* (for low mimosine content), guinea grass, *Setaria*, stylo, *Medicago*, *Vigna* and *Urochloa* species in Australia (*22*).

During the past 25 years researchers in tropical and subtropical Australia have taken the leadership in grass and legume plant exploration, introduction and evaluation, and improvement by selection and breeding. More than 50 selections and cultivars have been registered or recognized (*9*). The CSIRO Division of Tropical Agronomy 1974-75 report (*22*) listed more than 80 senior and 60 technical staff working full time in pasture agronomy and animal production as related to tropical and subtropical grass and legume evaluation. This undoubtedly exceeds that of any other continent.

Regions of Adaptation — Cultivated Forages

Grasses are cosmopolitan and comprise an essential component of the vegetative cover in the tropics and subtropics. Recognized grasslands have been delineated and described, but this is not a characteristic of legumes. The latter are less widely dispersed than grasses, but occur as constituents of many grasslands. Most species listed in Table 1 thrive in their native regions, and many have been transported to other parts where some now exist as naturalized components of grazing lands. They flourish over a wide range of environmental conditions, especially when soil nutrient deficiencies are corrected and water is available.

Tropical Boundaries — The usually accepted tropical boundaries extend over the area of 23° 27' north and south latitudes, i.e. from the Tropic of Cancer to the Tropic of Capricorn. This region contains about one-fourth of the earth's land area and 40 percent of total surface. It receives over one-half of the total rainfall. Prevailing temperatures favor year-round growth of grasses and legumes, except at the higher elevations. The subtropics lie immediately north and south of the solar tropics. A limit has not been precisely defined but is taken to be about 35° north and south of the equator.

It has been suggested that the transitional zones of tropical vegetation near the 30° latitudinal lines might be considered as boundaries of the biological tropics (*23*). There could be no definitely designated lines, since the tropical vegetation fluctuates above and below thirty degrees. This is particularly noticeable for the type and composition of grasslands. On a global basis, approximately one-half of the earth's grazing lands lie within the biological tropics. They cover a wide range of environments from very humid conditions to the arid lands of the desert fringes, and from sea level to very high elevations.

Grazing lands and potential for improvement — Extensive areas of grasslands and

grass-woody associations which provide grazing lands occur on all continents and many larger islands. Large areas of the earth's grasslands have been destroyed by man's extension of agriculture where the climate, soil, and topography were suitable for arable crops. In some regions, the activities of man modified plant communities so that major grazing lands have developed where grasses at one time comprised a minor component of the vegetation in the natural state (*24*). It is estimated that almost 60 percent of Africa is covered with grasslands as well as wooded, low tree and shrub savannas which are used for grazing, 35 percent of Asia, 18 percent of Australia, and 45 percent of South America (*25*).

Sixty percent of the earth's cattle and 50 percent of the sheep and goats are found in the tropics and subtropics (*26*). These livestock produce more than one-third of the total earth's meat supply and one-sixth of the dairy products.

Any estimate of the proportion of grazing lands which have been improved by agronomic and cultural practices would be speculative. The 1973-74 Annual Report of CSIRO's tropical pasture division (*27*) noted that 60 to 70 million hectares are considered as potentially available for pasture improvement in Northern Australia. To date, only 4 to 5 percent has been improved. In Colombia, it has been estimated that improved grass species covered one-tenth of the 40 million hectares of naturalized or native grazing lands (*28*). These included species such as guinea grass, jaragua, Pangola, para, elephant, buffel and imperial which were sown or transplanted in some areas but were extended naturally into the native vegetation in other parts. In general, little or no use has been made of improved pasture management practices. The transformation from natural grasslands to sown pastures includes species replacement, application of fertilizers for plant establishment and maintenance, and grazing management. The term "improved pastures" is broadly applied and when writing, discussing, and reporting information about grazing lands, one must be careful to set forth a clear definition.

The tropical zones, where a distinct potential for increased livestock production on improved pastures can be expected, include the wet equatorial and monsoonal areas and encompass parts of the humid subtropics. These regions comprise approximately 27 percent of the globe's land surface, being classified as 33 percent wet tropics, 49 percent monsoonal and 18 percent subtropics (*8*). Vegetation of the tropical and subtropical arid regions provides a less favorable environment for cultivated grasses and legumes but can be improved by range management techniques.

Considerable potential exists for increased animal output in the tropics where it has been calculated that 20 percent is grazing land, 10 percent crop land, 35 percent forest, and a third wasteland (*26*). Within the tropics, herbage for grazing fluctuates with available soil moisture so that animal liveweight gains usually follow a "stop-and-grow" pattern. With low quality nutrition, slaughtered animals often produce carcass weights less than one-half that in the United States and Europe. By use of technical innovations based on present knowledge of pasture improvement, remarkable advances are possible. For example, it has been suggested that the cattle population in Venezuela could be increased from 8 to 24 million (*29*). A review of beef production potential in the Colombian Llanos Orientales, based on experimental data, showed that the area could produce up to 3.5 times that of the present output on a short-term basis but even more on a long-term basis (*30*). Data from Brazil demonstrated that with the introduction of improved, viable technology it was possible to raise the calf crop to 70-75 percent, increase the slaughtering rate to 22 percent, lower slaughter age to three years, and increase beef production per hectare to 120 kilograms per year — all being modified by 100 percent or more. Such striking responses are easier to demonstrate than to implement, so that optimism must be tempered with the reality of environmental limitations, restrictions of research structures and extension activities, constraints of credit and marketing systems, and developing land tenure organizations (*31*).

Species Adaptation — A vast majority of the cultivated grass and legume species and cultivars possess a broad genetic diversity and perform well over a wide spectrum of soil and climatic conditions. Sufficient testing of cultivated types has been carried out to indicate response under water and temperature stresses, soil nutrient requirements, and photoperiodic effects. A few examples will serve to illustrate

the importance of environmental influences. Although widely distributed over the tropics and subtropics, *Leucaena* occurs more frequently in regions where soils are well supplied with calcium. *Glycine* is less tolerant of acidic soils than most tropical legumes, but two selections, Cooper and Clarence, made in Australia increased the range over which this species can be utilized (*8*). Townsville stylo thrives well on soils low in phosphorus content, because of the capacity to absorb greater quantities of this element per unit weight of root tissue per unit of time than other legumes (*32*). The perennials stylo, centro and puero do not tolerate cooler subtropical temperatures, but are highly dependable in the wetter tropics. Most grasses prefer the more moist regions, with types such as para and German grass prospering in the low wetlands and flooded areas. Drought-resistant grasses include buffel, Rhodes, bahia, green panic, Columbus grass and sabi grass. Kikuyu is intolerant of high temperatures and thrives best in cooler regions. Pangola grass, although a single genotype, yields well on fertile soils with ample soil moisture, but plant growth declines when night temperatures are cool. Thus, in Puerto Rico, Giant Cynodon is referred in the mountainous regions, since it continues growth at lower temperatures.

Climatic homologues — Regions with homologous climates and similar vegetational associations have been identified (*33*, *34*) so that plant collectors can narrow their search for specific types and concentrate on analogous ecological environments. An agrostological index was prepared by surveying floristic lists available in world literature and arranging the predominant grass species into class intervals (*33*). Certain localities had almost identical class groupings, e.g. British Honduras and the Ivory Coast, Ceylon and Formosa. Several had like indices for some grass tribes but unlike indices for others. A number of plant explorations from Australia were made by using information from similar agroclimes supplemented with other information. For example, a close coincidence of the natural distribution of buffel grass was noted between Central Australia and parts of Africa and Asia. Subsequent explorations led to the introduction of valuable materials from these regions into Australia. The findings suggested that the pasture agronomist should give more attention to climatic homologues when accumulating species and cultivars for testing.

Potential Yields of Grasses and Legumes

Annual dry matter yields of grasses vary from less than 0.5 tons/ha in the arid *Aristida* native grasslands of the sub-Sahara to more than 100 tons/ha in heavily fertilized elephant grass plantings of the humid, lowland tropics. Herbage produced by legumes fluctuates, but the accumulated biomass of forage does not approach the potential of grasses. This difference reflects the higher net leaf photosynthesis rate of tropical cultivated grasses than those of legumes (*35*). Annual dry matter yields selected as being among the highest recorded in experimental plots are shown in Table 2. Greatest yields occurred in the humid tropics where water was not a limiting factor. In these areas, the daily energy input (*36*) is lower (400 to 500 cal/cm^2 per day) than in the subtropics (sometimes exceeding 750 cal/cm^2 per day). Little seasonal variation prevails, however, so that growth continues throughout the year with adequate soil water and nutrients. In the temperate and subtropical regions, growth declines during periods of low temperature, but the extended day during the summer months allows increased seasonal production.

The high dry matter yield of 130 ton/ha in Colombia (*37*) came during the first year with cuttings made at 9-week intervals, nitrogen applied every six weeks, and supplemental irrigation provided during periods of water stress. The 86.0 ton/ha yield in Puerto Rico (*38*), however, represents a 3-year average, harvests made every 9 weeks and no irrigation. These yields greatly exceed those commonly obtained, but it is not unusual to encounter reports of more than 40 ton/ha during the growing season in the wet tropics (*38*, *39*, *41*). In the subtropics, seasonal water stress limits production, and dry matter yields of the more productive species rarely exceed 25 to 30 ton/ha. More often, yields of 10 to 15 ton/ha are reported (*42*, *43*, *44*).

Response of grasses to nitrogen — The spectacular effects of nitrogen applied to responsive grasses is depicted in Figure 3-1, which shows curves fitted to data from several sources (*39*, *40*, *43*, *45*, *50*). Most fertilizer studies have been conducted with pure grass stands, located

Table 2. Annual yields of selected grasses and legumes

Climate and Location	Species	Dry matter ton/ha	Applied N kg/ha
Tropical		*MT*	*kg*
1. Naitaima, Colombia (39)	*Pennisetum purpureum*	130.0	1,320
2. Puerto Rico (40)	*P. purpureum*	86.0	2,244
3. Naitaima, Colombia (39)	*Hyparrhenia rufa*	56.7	400
4. Puerto Rico (40)	*Panicum maximum*	54.0	1,795
5. Guadeloupe (45)	*Digitaria decumbens*	54.6	800
6. Mauritius (46)	*Leucaena leucocephala*	34.6	—
7. Ivory Coast (47)	*Stylosanthes guianensis*	17.4	—
Subtropical			
8. California (41)	*Medicago sativa*	32.4	—
9. Texas (48)	*Cynodon dactylon*	31.8	1,422
10. Queensland (44)	*Pennisetum clandestinum*	30.0	1,120
Temperate			
11. Te Awa, N.Z. (49)	*Lolium perenne*	26.6	Adequate
12. Te Awa, N.Z. (49)	*Trifolium pratense*	26.5	—

on soils previously cropped and fertilized, with the herbage removed. Grass species respond differently and some, such as molasses grass, do not benefit greatly with application of nitrogen. Dry matter production of other grasses, such as elephant, guinea, pangola and *Cynodon* increases linearly with amount of nitrogen — up to 600-800 kg/ha. The slope becomes less pronounced beyond 1,000 to 1,200 kg/ha. Studies in Puerto Rico (*40*) showed that 6 well-managed cutting grasses, yielding about 25.0 ton/ha annually, removed an average of 340 kg/ha of nitrogen, 55 kg of phosphorus, 445 kg of potassium, 128 kg of calcium, and 78 kg of magnesium in the harvested herbage. Such quantities of nutrients cannot be supplied by even the most fertile soils.

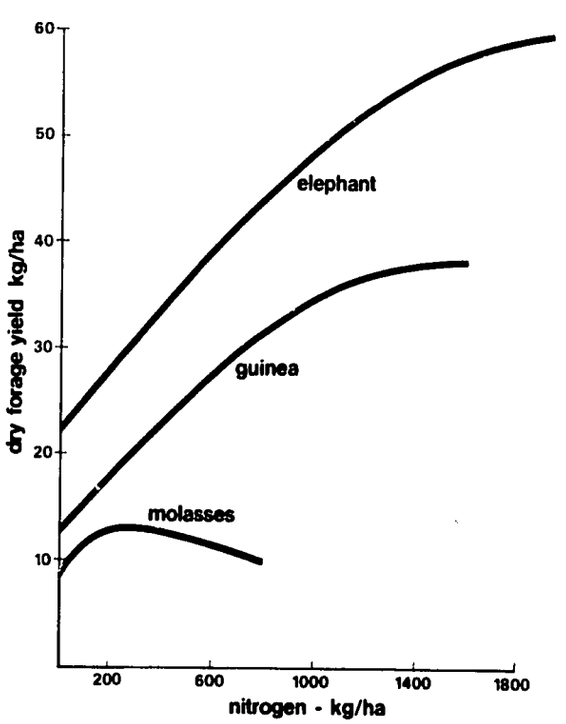

Figure 3-1. Response of grasses to applied nitrogen; forage cut and removed (*39, 40, 43, 45, 50*).

Applied nitrogen usually depresses soluble carbohydrates, increases crude protein, has little effect on cell wall proportions, and tends to increase lignification (*51*). Nitrogen response is more striking in seasons of rapid growth than during drier and cooler months. Crude protein drops with an increase in herbage production and is highest during periods of slow growth. Most studies show that dry forage produced per kg of applied nitrogen sharply declines with increasing rates of nitrogen. At 200 to 600 kg/ha of nitrogen, from 30 to 50 percent is recovered in the harvested foliage. Above these levels, the recovery drops to 10 and 20 percent (*17, 39, 40, 43, 50, 52*).

Crude protein content of grasses rises sharply with increasing levels of nitrogen. With applied nitrogen the grass herbage frequently contains from 15 percent or more of crude protein on a dry matter basis during the growing season

but may drop to 5 percent or less in the dry season. It appears that the increased nitrogen content of fertilized grass comes in part with luxury consumption of this nutrient. Different sources of nitrogen do not significantly alter forage production, but ammonium sulfate and urea measurably reduce soil pH.

It is unlikely that the forage yields of the livestock farmer will approach those of experimental conditions. Under intensive management, however, high levels of output can be expected. For example, a dairyman near Medellin, Colombia (460 m in elevation) grew elephant grass and practiced soiling, made cuts every 30 to 40 days, and harvested 40 to 50 tons/ha of fresh material each time (personal communication). After every second cutting he passed a horse-drawn cultivator between the rows of grass to incorporate the manure and stable refuse and to open channels for irrigation, thus keeping the soil aerated. Washings from the milking stalls were collected and returned to the grass planting. Supplemental water was supplied by gravity flow during periods of moisture stress. Annual dry matter yields were calculated at about 75 tons/ha, an amount sufficient to maintain 15 milking grade Holsteins, which were supplemented with 1 kg of concentrate per 4 kg of milk.

Oversown Legumes — In areas with a prolonged dry season, Townsville stylo is an appropriate legume and can be established by seeding in burned grassland followed by heavy grazing in the wet season to reduce grass competition (*53*). Animal response on Townsville stylo-native speargrass (*Heteropogon contortus* (L.) Beauv.) illustrates the value of this annual legume under Australian conditions of 750 to 1,000 mm yearly rainfall (Table 3). The combination of fertilizer and legume gave a six-fold increase in beef gains/ha and almost doubled the liveweight gain/head as compared to speargrass alone. Furthermore, increased animal output was associated with a more rapid turnover of slaughter stock, which reduced maintenance costs per animal (*54*).

The impact of this legume on quality herbage available for grazing was also demonstrated in the Northern Territory of Australia (*55*). Three different studies were made: (a) steers on native grazing land and then Townsville stylo during sequential seasonal periods; (b) steers rotated on native grazing land and Townsville stylo for a given number of days; and (c) steers on paddocks with different percentages of Townsville stylo. The substitution of legume for native grass in each study resulted in a progressive, linear improvement in liveweight gain. Over a 630-day period (wet and dry seasons), animals with access to native grass gained 60 kg/head, and with full access to Townsville stylo 280 kg/head. During the dry season, steers on native grazing land lost 40 kg/head, whereas those on Townsville stylo pastures gained 60 kg/head over 112 days. Caribbean stylo (*Stylosanthes hamata* cv. Verano), a cultivar recently released in Australia, is an erect, smooth-stemmed, herbaceous perennial which outyields Townsville in dry matter and produces slightly higher liveweight gains. It also grows on a wider range of soil types and shows greater drought tolerance (*56*).

Stylosanthes guianensis used to complement naturalized grazing land in Northern Nigeria gave similar results when animals were allowed night access to the legume (*57*). This legume does not establish well by oversowing without some rudimentary form of soil disturbance and performs best on a well-prepared seedbed. For example, in the Ivory Coast, carrying capacities under different grazing schemes were determined as follows: (i) Bush savanna (native grazing land) — 0.25 head/ha (N'dama cattle weighing about 300 kg); (ii) Cleared savanna with natural grasses — 0.5 to 1.0 head/ha; (iii) Disked natural grazing land oversown with stylo — 1.5 head/ha; (iv) Well-prepared seedbed sown with stylo, where a few naturalized grasses persisted — 3.0 head/ha; and (v) Savanna cleared, land prepared, guinea grass transplanted in rows (20 x 50 cm), fertilized and irrigated — 13.0 head/ha (*58*).

Studies of oversowing other legumes into established grasses have largely been carried out in small experimental plots (*59*). Established stands have varied from poor (extremely sparse plant density) to good (25 to 30 percent legume). The higher plant densities were usually associated with more intensive land tillage practices which provided favorable seedbeds and with phosphate fertilization. Even with fair establishment, a serious problem noted with most legumes was persistency beyond the year of seeding, particularly observed in arid and semi-arid regions where moisture stress commonly occurred. Most trials, whether on large or small scale, involved hand sowing or

Table 3. Annual production from Townsville stylo and speargrass grazing land in southeastern Queensland, 1959-66

Treatment	Stocking rate	Gain/head	Gain/ha
	no./ha	*kg*	*kg*
Native grass	0.28	83	25
Native grass + fertilizer[1]	0.61	100	62
Native grass + T. stylo	0.74	121	93
Native grass + T. stylo + fertilizer	0.95	149	148

[1] Annual dressing of superphosphate (125 kg/ha), molybdenum (37.5 gr/ha) and potassium chloride (63 kg/ha).
Source: (*54*)

use of mechanized equipment. In some instances aerial seeding has been practiced (*57*, *60*).

Introduction of a grass into established legumes has received little attention in the improvement of pastures. Undoubtedly this is due to the general predominance of grasses in grazing lands so that greater attention has focused on methods of incorporating a legume into the existing vegetation and its maintenance so as to comprise a significant component of the herbage available for grazing. Grasses have been used for oversowing native and naturalized grazing lands and reseeding denuded areas caused by overgrazing, wind, and water erosion (*61*). Climatic conditions of the area largely determine the choice of methods and species to be used. The degree of successful establishments, however, usually increases with the intensity of cultivation and the need for land tillage increases as expected rainfall decreases.

Value of legumes in pastures — The contribution of legumes in combination with grasses had been documented by studies in Australia, as illustrated by the curves shown in Figure 3-2 (*62*). Data used to construct this graph were taken from several experiments: (a) The curve of 1 percent legume represents a pasture which produced about 20 kg liveweight gain annually in a rainfall area of 600 mm; (b) an unfertilized Dallis and carpet grass pasture which contained 5 to 9 percent white clover and yielded about 100 kg/ha of liveweight gain in a region with slightly more rainfall; (c) Pangola grass pastures which had 20 and 30 percent legume content (a mixture of Green and Silverleaf Desmodiums, Siratro, phasey bean Lotononis and white clover) in an area of 1,650 mm annual rainfall; and (d) A Pangola grass pasture fertilized with approximately 400 kg/ha of nitrogen and grazed with about 5.0 animal units/ha. A significant feature of the graph is the increased liveweight gain with different percentages of legume in the available herbage. Under the climatic conditions of southeast Queensland, these curves reflected a decline in production during the cooler months, but showed a high overall rate

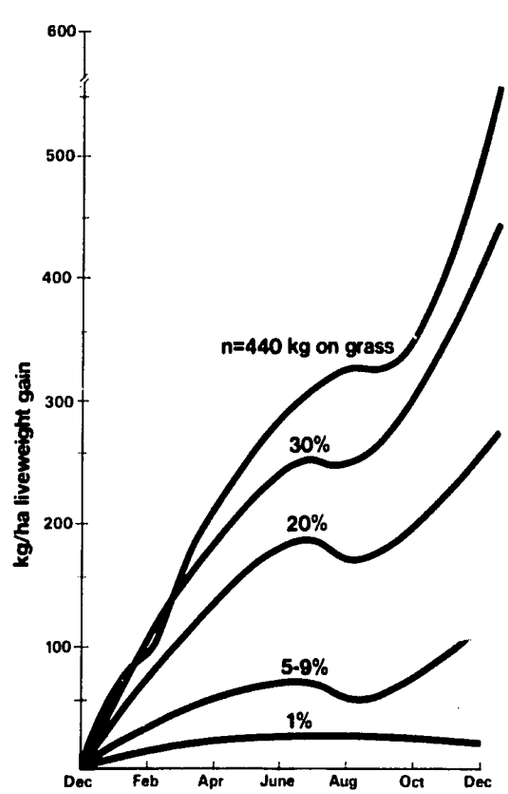

Figure 3-2. Effect of legume-grass combinations and fertilized grass on beef cattle liveweight gains. Redrawn from data in Australia (*62*).

of gain throughout the year. Presence of the legume provided an increased supply of crude protein for animal production, as well as a greater intake of digestible dry matter. At the indicated botanical compositions, grasses gained little benefit from nitrogen being fixed and transferred by the legume. It has been calculated that the legume component must exceed 40 percent before the protein content of associated grass is improved. As available protein from the companion legumes increases, however, animals more effectively utilize the grass of lower nutritive value.

In the Philippines (*63*), grasslands dominated by *Imperata cylindrica* (L.) Beauv. (Cogon grass) were grazed with one animal unit/ha. In addition, two improved pastures were established, one by burning the grass, preparing the land and transplanting pará grass and the other by sowing centro with pará (Table 4). With the improved pastures, herbage production and liveweight gains/ha were tripled, or nearly so, as compared to the native cogon. A higher percentage of the herbage was consumed and weed invasion was markedly reduced with the use of a legume. Increase in weed composition of the cogon and the pará grass at the 200 kg/ha level of nitrogen reflected overgrazing and deterioration of the pasture. Subsequent studies showed that stylo could be established on cogon grassland by burning or heavy grazing, disking lightly, applying 50 kg/ha of phosphate and oversowing the legume (personal communication).

Grass-legume mixtures — The number of different species comprising a pasture mixture varies from a single grass and legume (simple) to 6 or 8 legumes and 3 or 4 grasses (complex). For the development of long-term improved pastures it is advisable to include at least two compatible grasses and two legumes. A perennial grass companion is desirable to (i) increase total herbage production, (ii) insure stability of production, (iii) increase the energy value of the pasture, and (iv) suppress the invasion of weeds. Legume species are included in the mixture to (i) increase the amount of crude protein available to the grazing animal, (ii) extend the grazing period into the dry season, and (iii) provide nitrogen for the companion grass. The permutations of grass-legume combinations far exceed their practicality of use. Many have been examined under small plot clipping trials for short durations (*39*, *64*). It is easy to compound mixtures but their establishment in pastures, and particularly their maintenance, is largely dependent on climatic conditions, soil environment and its modification, a regularized fertilization program, animal management practices, and managerial skill of the grazier.

Maintenance of an appropriate grass-legume balance in an improved pasture requires strict attention to the overall soil-plant-animal management program. Generally, the percentage of legume declines over time, in which event legumes make an insignificant contribution to the total herbage available for grazing. In fact, a high percentage of pastures and grazing lands in the tropics and subtropics is comprised largely of grasses, frequently in mixture with undesirable species. The renovation of deteriorated grazing lands by conventional techniques may not be economical or satisfactory unless

Table 4. Beef production on cogon grass, para' grass and centro, Mindanao, Philippines[1]

Pasture	Fertilizer N-P_2O_5-K_2O	Stocking rate[3]	Liveweight gains per head: Daily	Liveweight gains per head: Annually	Herbage production	Consumption	Weeds
	kg/ha/yr	*AU/ha*	*kg*	*kg*	*ton/ha*	*Percent*	*Percent*
Cogon	0- 0-0	1.0	0.27	100	14.5	34	59
Pará + centro[2]	0-50-0	2.0	0.42	153	56.4	41	18
Pará	100-50-0	2.0	0.36	130	40.2	44	26
Pará	200-50-0	3.0	0.28	104	41.7	53	47

[1] Nitrogen split into two applications; liveweight gains significantly different.
[2] Centro comprised 24 percent of mixture at beginning of trial.
[3] Animal unit per hectare
Source: (*63*)

considerable attention is given to some means of tillage of the old sod, use of applied fertilizers (especially phosphate for legumes), and appropriate grazing management practices.

Legumes and browse plants as supplementary feed — An alternative would be the use of sown legumes which are maintained as supplementary feed. *Leucanea leucocephala*, which is actually a tree but becomes a shrub under grazing and browsing, has greater potential than any other tropical or subtropical legume. It is deep-rooted, drought-tolerant, adapted to a variety of soils and pantropic (*65*). Plants can be grown along hedge rows or fences and established in solid stands or in combination with grasses. In Australia, experimental results show that seeds can be sown in rows about three meters apart, cultivated until plants become established, after which they are interplanted with grasses such as Pangola, guinea or sabi (*26*). Leucaena seedlings can also be transplanted into established grass pastures. This method provides a highly productive two-canopied pasture. Leucaena herbage often exceeds alfalfa in nitrogen content, but may possess up to 0.5 percent of the nitrogen as mimosine, an undesirable constituent which can cause disorders in monogastric animals. The bovine rumen degrades mimosine so that measurable increases in liveweight gains of beef cattle and milk production of dairy cows can be obtained when grazed on Leucaena (*66*). Diets containing large quantities of Leucaena may cause wool shedding and abortion in sheep, loss of hair in horses from the mane and tail, and loss of hair in pigs. Adjustment of Leucaena intake helps to alleviate these conditions.

In many parts of the subtropics and higher elevations of the tropics, alfalfa provides supplemental feed when grazed or cut daily and fed. It does not persist in lowland, humid areas (*67*). Other legumes sometimes used, or which have potential as supplemental forage, include *Aeschynomene americana*, *Cajanus cajan*, *Clitoria ternatea*, *Lablab purpureus*, *Macroptilium phaseoloides*, *Macrotyloma axillare*, *M. uniflorum*, *Peueraria phaseoloides*, *Stylosanthes species*, and *Vigna luteola*. In many countries a number of browse plants and fodder trees provide desperately needed herbage during dry periods (*68*). Leaves of many species exfoliate in the midst of the dry season, long before the initial rains, and account for the only source of feedstuff. Their nutritive value and digestibility are equal to that of highly prized herbaceous legumes. In some regions, certain species are cultivated, but their potential has never been fully exploited. There is a great need for surveying fodder trees and shrubs used for supplementary feed, to be followed by their collection, evaluation, maintenance, multiplication, and utilization.

Fertilized grass — In terms of maximizing beef production fertilized grasses which respond to applied nitrogen have the greatest potential in regions with 1,200 to 1,500 mm annual rainfall and more, or where supplemental water is available for irrigation. A comparative estimate of beef production under different management systems is given in Table 5. These data represent a compilation of several experiments reported in the literature (*69*). Yields from fertilized grass varied widely from region to region due to differences in total rainfall and distribution, soil fertility, botanical composition of the grazing land, amount of fertilizer used, breed of cattle, and stocking rate.

The potential liveweight gain based on theoretical expectation was exceeded in north Queensland. Irrigated Pangola grass pasture which was topdressed at frequent intervals with nitrogen and rotationally grazed produced 2,100 kg/ha (*52*). In Florida, steers on St. Augustine reportedly gained one ton of beef per acre (approximately 2,200 kg/ha live-

Table 5. Beef production liveweight gains in monsoonal and tropical climates[1]

Type of pasture and treatment	Climate	
	Monsoonal	Humid tropics
Natural grazing lands	*Kg/ha*	*Kg/ha*
Improved grazing management	20	90
Legumes oversown, fertilized	150	400
Cultivated pastures		
Grass-legume mixtures, fertilized	250	600
Nitrogen-fertilized grass	550	1,650

[1] Calculations based on data from 21 grazing experiments on various continents. (*69*)

weight gain), when animals were given a daily supplement of 450 g of cottonseed meal (*70*). This output has not been repeated in subsequent trials. Studies over a 10-year period, however, showed daily liveweight gains of 6.35 kg/ha during the summer months, but only 0.8 kg/ha during the winter period (*71*).

In Puerto Rico (*72*) beef production of intensively managed guinea, elephant, and Pangola grass pastures was compared with that of elephant grass fed as fresh, chopped forage. The pastures and elephant grass planting received a yearly total of 1,650 kg/ha of 14-4-10 fertilizer topdressed in 6 applications. Irrigation was supplied as needed to provide 380 mm of water weekly, including rainfall.

Increasing the quantity of applied fertilizer gave higher liveweight gains/ha when steers grazed elephant grass pastures on steep hillslopes of Puerto Rico (*40*). Use of 4,400 kg/ha of a 15-5-10 fertilizer, split into 4 dressings per year, boosted liveweight gains/ha by 67 percent and carrying capacity by 64 percent as compared to 1,760 kg/ha of the same fertilizer (Table 6). Average daily gains per animal were not significantly altered with increments of topdressed nutrients, a property commonly noticed when yields of grass are increased by applied nitrogen.

In Queensland (*59*) annual liveweight gains of steers on Pangola grass were (i) 1,106 kg/ha with 448 kg/ha of nitrogen and 5.6 animals/ha, and (ii) 699 kg with 168 kg of nitrogen and 4.3 animals/ha. Fertilized Pangola grass pastures in the Caribbean gave liveweight gains of 1,180 kg/ha in the Virgin Islands (*73*) and 1,228 kg/ha in Jamaica (*74*). In Brazil, 200 kg/ha of nitrogen applied to guinea grass raised liveweight gains of Zebu steers to 704 kg/ha as compared to 301 kg for the no-nitrogen treatment (*75*). Stocking rates averaged 3.54 and 1.38 steers/ha and daily gains totaled 0.49 and 0.56 kg/head, respectively, for the nitrogen and no-nitrogen treatments.

Continued high animal output from fertilized grass or grass-legume pastures depends to a great extent on the managerial skill of the cattleman and his ability to administer appropriate grazing management practices. Cattle numbers must be adjusted to the available herbage, even with irrigation. Intensive ration grazing may be warranted under conditions of rapid plant growth.

Recycling of nutrients — The soil nutrient status should be monitored and used as a guide to adjust applied fertilizer rates. When pastures are grazed, about 80 percent of the nitrogen, phosphorus, and potassium consumed is returned in the excreta. Thus, the animal is an important component in recycling nutrients of the soil-plant-animal system (*76*). Higher stocking rates accelerate the turnover of nutrients, resulting in a greater retention of nutrients in the system. The high return of nutrients might suggest that the need for pasture fertilization could be reduced. Grazing animals, however, do not effectively distribute their excreta but deposit heavy concentrations in limited areas resulting in leaching, particularly of nitrogen (*77*). Furthermore, "manure spots" are generally avoided by grazing animals, thus reducing overall herbage consumption. In parts of Africa and Asia dung beetles carry out the very important task of clearing away the animal droppings, and thus accelerate the rate of nutrient recycling. Recently, species of dung beetles were imported into Australia where some became successfully established (*78*).

Table 6. Effect of nitrogenous fertilizer on annual production of intensively managed elephant grass pastures in Puerto Rico, 5-year average (*40*)

Fertilizer	Daily gain/head	Liveweight gain/ha	Carrying capacity/ha[1]	T.D.N. consumed/ha[2]
kg	*kg*	*kg*	*no.*	*kg*
1,760	.635	1042	5.4	7,580
3,080	.590	1410	7.2	9,855
4,400	.590	1740	8.9	12,210
$LSD^{0.5}$	N.S.	270	1.0	1,386

[1] Calculated from body weight, days of grazing, and gains in weight.

[2] Based on one 660 kg animal making normal gains = 3.86 kg T.D.N. daily.

Under intensive grazing conditions, animal parasites may become a severe problem, especially in moist tropical areas. This calls for additional attention to animal health and sanitation. Furthermore, it may necessitate the rotation of arable crops as a part of the pasture management system.

On the basis of the foregoing discussion on potential yields, it seems apparent that:

1. A strong potential exists for increased liveweight gains in the humid and monsoonal tropics and subtropics by using cultivated species of grasses and legumes.

2. The tremendous potential is not within easy reach of most livestock keepers because of the modifications and inputs needed to transform native and naturalized grazing lands to highly productive improved pastures.

3. Oversowing appropriate legumes would be the most logical and reasonable approach as a first step in the improvement of most grazing lands.

4. Cultivated grass-legume pastures have about one-half the potential in terms of beef production as that of fertilized grasses, but in view of foreseeable energy (fuel) shortages they present a more desirable alternative to increase world meat supplies than fertilized grass.

5. The most striking increase in beef production can be attained with grasses which respond to heavy applications of applied fertilizers, especially topdressed nitrogen.

Legumes in Tropical and Subtropical Grazing Lands

Forage legumes are characterized by a symbiotic relationship with bacteria which infect their roots and combine atmospheric nitrogen into a form utilized directly by the legume and made available to associated plants. The bacteria depend on the legume for other basic nutrients needed to sustain their life functions.

Legumes are desirable components of improved pastures and grazing lands where (a) nitrogen is a limiting factor for optimal growth of associated grasses; (b) a need exists for increased crude protein in herbage available for grazing; and (c) extended grazing into the dry season is desired. Legumes remain green when growth of grasses declines with the onset of drought. Most legume species have a tap root

Irrigated Alta fescue in Mexico. *Photo by Winrock International.*

which penetrates deeper into the soil than the fibrous roots of grass. In addition, the enlarged root section just below the crown of many legume species provides a nutrient and water reserve during stress periods.

Few tropical legumes develop crown shoots as does alfalfa, but new tillers arise from leaf axils. New growth also develops from apices of the main stem as well as side and axillary branches. The stems of trailing and decumbent types such as centro, Desmodium, Glycine, puero, calopo, and Siratro possess long intermodes. Poor rooting occurs at the nodes as contrasted to white clover. Thus, when stems of tropical legumes are damaged by the hooves of trampling animals there is little chance of regenerated growth.

Under humid conditions, flowering and seed set of tropical legumes are nonuniform and spread over a long period of time. Plants remain green into, or through, the dry season so that seed set occurs within the mass of fresh herbage, presenting a problem of ripening and harvesting. When seed pods mature, those of some species such as centro, Siratro, puero, Clitoria, and Leucaena readily dehisce causing significant loss of seeds by harvest time. By the time of maturity, the seed coat of most legumes has hardened and is impermeable, or nearly so, to imbibition of water. For rapid germination, some form of seed scarification is necessary, such as (a) mechanical treatment to fracture the seed coat (usually occurs with mechanical seed harvesters and during processing); (b) use of sulphuric acid for 2 to 5 minutes followed by thorough washing; (c) soaking for 5 minutes in water brought to a boil, or heated to 80 degrees C then rapidly cooled, and (d) passing through the rumen of grazing animals.

In reviewing the presence of legumes in pastures, consideration should be given to three symbiotic relationships: (a) legume/*Rhizobium* symbiosis; (b) legume/grass symbiosis; and (c) plant/animal symbiosis.

Legume/bacteria symbiosis — Fixation of nitrogen by legume/*Rhizobium* symbiosis is influenced by the presence of an effective strain of *Rhizobium*, availability of soil and plant nutrients, environmental conditions, competition of associated vegetation, and intensity of grazing. A majority of tropical legumes are readily infected with a wide range of "cow-pea" rhizobial types commonly present in soils of the tropics and subtropics, e.g. calopo, stylo, Townsville stylo, Glycine, puero, phasey bean, Siratro, pigeon pea (*79*). Some tropical legumes require a specific type of *Rhizobium* for effective nodulation and nitrogen fixation: centro, Lotononis, most Desmodiums, finestem stylo and Leucaena. An efficient strain of *Rhizobium* must be readily accessible to the legume seedling for effective symbiosis. Associated grasses are considerably more efficient in the uptake of soil nitrogen than legumes, so that the latter are highly dependent on fixed nitrogen in competitive growth (*80*). Commercial innoculants of both the non-specific and specific strains of *Rhizobium* are generally available.

Cowpea types of rhizobia tolerate acid soil conditions and produce alkaline end-products during growth (*81*). In contrast, legumes which are adapted to alkaline soils, such as alfalfa, white and red clovers, produce acidic endproducts. Most tropical legumes are also tolerant of acid soils and possess a high efficiency in the extraction of calcium from soils low in this element (*82*). This behavior of the tropical legumes and their associated rhizobia forms the basis for liming in the establishment and maintenance of tropical as compared to temperate legumes. Additions of limestone are rarely needed, especially if superphosphate dressings are made, except in very poor and highly acidic soils. An exception is the cultivation of Leucaena which responds to liming and molybdenum application in acid soils. This legume requires a specific *Rhizobium* with a slightly alkaline end product (*79*). These results stress the need for selecting, testing and maintaining the appropriate rhizobia. Much credit in this field goes to Australian researchers who have taken the leadership in collecting and evaluating rhizobia in collaboration with explorations and introductions of legumes (*83*).

Even with the appropriate innoculum and formation of nodules, the legume-associated *Rhizobia* are unable to function without a satisfactory level of nutrition. Calcium is required as a nutrient for proper growth and functioning of the legume and bacteria, even though applied limestone may not be essential to modify an acidic soil condition. Phosphorus deficiency in many soils is the most limiting factor in the establishment and maintenance of the legume. Limited plant growth, of course, restricts the total amount of nitrogen fixed by the *Rhizobium*. Other nutrients needed in the performance of legume symbiosis in-

clude molybdenum, which functions in the nitrogen fixation process (*84*) and sulphur, which is an essential element in formation of proteins (*85*).

Amount of nitrogen fixed — Cultivation of leguminous plants provides the most economical means of adding nitrogen to the soil-plant-animal system. Determination of the amount of fixed nitrogen depends on measuring (a) the yield of nitrogen in harvested above-ground plant material; (b) the change in the content of soil nitrogen; and (c) the difference in yields of grass-legume mixtures and that of nitrogen fertilized grasses (*86*). Studies have shown a wide range in quantities of nitrogen fixed, but the amounts were generally comparable under tropical and temperate conditions. For example, yields of 580 kg/ha in Australia (*87*) and 462 kg/ha in Hawaii (*88*) produced by Leucaena approached the 600 kg/ha/year measured for white and red clover in New Zealand (*89*). In Hawaii, nitrogen fixation varied between 97 kg/ha annually with *Desmodium canum* to 264 kg/ha with *D. intortum* in mixtures with Pangola and over 300 kg/ha with *D. intortum* in mixture with Kikuyu grass (*90*). The contribution of *D. uncinatum* in mixture with Setaria increased from 67 kg/ha of nitrogen fixed in the first year to 159 kg/ha fixed in the fourth year in Kenya, the latter being equal to grass fertilized with 200 kg/ha of nitrogen (*91*). Differences in the amount of nitrogen fixed by legumes (*52*, *92*) can be directly related to legume yield (*93*). This may be a reflection of genetic plant growth potential, environmental effects such as soil and water relationships, or influence of stocking rate. Studies in Queensland indicated that approximately 3,000 kg/ha of legume dry matter must be accumulated to obtain fixation of 100 kg/ha of nitrogen (*94*).

Legume/grass symbiosis — In the legume/grass symbiosis, direct transfer of nitrogen from legume to grass may be nil, or range up to about 5 percent (*80*, *90*, *95*). There is no conclusive evidence of an active process whereby nitrogen from legume nodules is directly transferred to associated non-legumes. It is likely that a passive release of nitrogen occurs from healthy tops and roots, but of greater importance is nitrogen made available from leaf fall and the normal senescence, death, and decomposition of older tissue. The main mechanism of nitrogen release from nodules occurs by their sloughing-off and subsequent decay, after which nitrogen becomes a part of the soil nutrient solution and is taken up by roots of the associated grass.

An outstanding feature of the herbage available for grazing in a legume-grass association is the constancy of nitrogen content of the legume component (*96*). Only small changes in crude protein and phosphorus content were noted during growth and increasing age of centro in Nigeria (*97*), Siratro, Greenleaf Desmodium and Glycine in Australia (*93*) and other tropical legumes in Trinidad (*98*). In Queensland *in vitro* dry matter digestibility of Siratro was relatively unchanged as plants matured, being 69.0 percent in 4-week old herbage and 65.5 percent in 16-week old herbage (*93*).

The voluntary intake of tropical legumes usually exceeded that of tropical grasses when fed to sheep kept penned for digestibility studies in Australia. This was attributed to the shorter retention time in the rumen and greater density of material. Studies with Pangola grass-legume mixtures showed that total intake increased with a higher proportion of legume in the diet. Furthermore, increased legume content resulted in higher intakes of grasses, even though their nitrogen content had declined (*99*).

Plant/animal symbiosis — Output of the grazing animal provides a sensitive measure of the quality and quantity of available pasture herbage. The legume component in the plant/animal symbiosis not only enhances liveweight gain and milk production but also increases the conception rate and decreases calf mortality. Legume-grass pastures in Florida gave higher percentages of calves weaned than fertilized grass — 85 and 64 percent, respectively (*100*). Application of superphosphate to Townsville stylo pastures in north Queensland improved breeding performance as well as beef production. Conception rate increased from 74 percent with annual topdressing of 110 kg/ha of superphosphate to 85 percent with 330 kg/ha. This compared to 66 percent conception rate of cows grazing an unfertilized pasture mixture of Townsville stylo and spear grass. Moreover, most cows on the unimproved pasture conceived every second year. The increased conception on fertilized legume pastures resulted from improved nutrition of herbage and of lactating cows during mating (*101*). Legumes

such as Townsville stylo, Siratro, Leucaena, *Stylosanthes guianensis* and *S. subsericea* grow in soils with low phosphorous. This may be due in part to the mycorrhizal association with their roots which aids in the extraction and utilization of phosphorus (*102*). The phosphorus content of legumes in such soils frequently drops below 0.10 percent and is inadequate for maintenance of animal health. The critical plant level of this nutrient (defined as the quantity needed for optimal growth, above which no additional growth would be expected and below which additional growth would be expected, if the element concerned were to be added) and others has been established from studies in Australia (*103*). For example, optimal forage yields of Townsville stylo occurred when herbage contained 0.17 percent of phosphorus, centro 0.16 percent, Glycine 0.23 percent and alfalfa 0.24 percent. Unfortunately, information about critical herbage levels may not be directly related to standards set for animal performance.

Grass-legume combinations provide a wider array of selectivity by grazing animals than grasses alone, but the proportion of plant species consumed may be different than the botanical composition of available herbage. At the Cunningham Laboratory in Queensland botanical compositon of oesophageal fistula samples showed preferential selection for *Urochloa* leaves following early rains after the dry season. This preference occurred in pastures where the green *Urochloa* leaves comprised only 10 percent of the dry matter available in pastures dominated by dry Townsville stylo (*22*). At the nearby Samford Station, the diet of grazing animals contained only 3 percent of Siratro in spring and early summer, whereas this legume comprised over 40 percent of the herbage consumed in autumn. Further study of penned animals showed that cows preferred autumn Siratro compared to summer-grown Siratro when free choice was allowed. This indicated that some change in the legume plant had affected acceptability. Additional studies are needed to clarify what modifications take place. The large leaves of legumes such as Siratro, Desmodium, and Lablab interfere with the biting behavior of grazing animals (*104*). Because of leaf size and lack of forage density, animals have difficulty in satisfying their nutritional requirements as contrasted to species with smaller leaves and more compact herbage.

Judicious grazing management becomes highly important in plant/animal symbiosis. The response of trailing and decumbent legumes such as Siratro, centro, puero, and *Desmodium* to heavy defoliation contrasts sharply to the permissable close grazing of Townsville stylo, Lotononis, and white clover. Their habit of growth requires that considerable leaf residual remain during or after grazing to allow continued and regenerated growth. In contrast, Townsville stylo thrives under close grazing. Heavy grazing pressure is needed to control excessive grass competition in Lotononis-based pastures but less severe than that of Townsville stylo (*93*, *105*). The stocking rate of stylo and Glycine falls between these extremes. Such knowledge is essential if the livestockman is to derive full advantage of grass-legume combinations.

Nitrogen Fixation by Organisms Associated with Tropical Grasses

Nitrogen fixation by microorganisms associated with tropical grasses holds tremendous potential for increased production of quality herbage and addition of nitrogen to the soil reservoir through recycling by grazing animals. Species such as *Andropogon*, *Brachiaria*, *Cynodon*, *Digitaria*, *Hyparrhenia*, *Melinis*, *Panicum*, *Paspalum*, *Pennisetum*, *Saccharum* and *Zea* have this capability (*106*). They all possess a carbon pathway (C_4 dicarboxylic acid) in photosynthesis which is more efficient than the C_3 pathway in temperate grasses (*107*). This results in higher net photosynthesis, greater energy conversion and increased growth potential as compared to temperate grass species. Wide variation occurs among grasses in nitrogen fixed by the associative organisms, but estimates of about 1.5 gm of nitrogen/ha/day have been made for Pangola and bahia grasses (*106*).

The bahia grass-*Azobacter paspali* association, described in Brazil, has been the most intensely studied (*108*). Activity of this organism occurred largely in the rhizosphere of grass roots, showing greatest activity during the growing season. Accumulation of nitrogen persisted into the dry season and enhanced growth and nitrogen content of herbage. Ecotypes of bahia and elephant grass differed significantly in nitrogenase activity on their roots; native forms of the grasses were more efficient nitrogen-

fixers. This suggested that commercial grass cultivars have been selected for response to higher mineral nitrogen levels. Such variability among grass types poses a challenge to plant breeders to promote this characteristic through breeding and selection.

The fate of fixed nitrogen was ascertained by studies of bahia grass growing in vermiculite with nitrogen-free solution (*106*). At no time did the grass plants display signs of nitrogen deficiency. After two months, the quantity of nitrogen had increased several-fold as plants developed. Plants contained a high percentage of the nitrogen but a significant quantity remained in the vermiculite, indicating that a portion would be made available to associated vegetation.

In Brazil, seasonal variation in nitrogenase activity was observed in elephant and Pangola grasses grown in the field, with and without applied nitrogen. Highest rates of nitrogen fixation occurred during the rainy season and when warm temperatures prevailed (*106, 109*). Additions of 20 kg/ha of fertilizer nitrogen every two weeks did not interfere with nitrogenase activity, even after application of 160 kg/ha. Further studies with bahia grass growing in pots showed a decline in organism activity with the use of an ammonium form of nitrogen but not with a nitrate form.

The discovery of nitrogen fixation in a broader spectrum of tropical grasses projects far-reaching implications in the development of forage-livestock feeding systems (*106*). The organism *Spirillum lipoferum* was found concentrated in the cortex cells of Pangola grass. This organism appears to be associated with the C_4 grasses which have malate as one of the primary photosynthetic products. *S. lipoforum* utilizes malate as an energy source and in association with grasses may be dependent upon them for this product as a substrate. Similar strains of *Spirillum* were isolated from guinea grass and other nitrogen-fixing grass species. In Florida, a *Spirillum* was found inside grass roots and surface-disinfected sections showed that nitrogenase activity was associated with the roots and not in the rhizosphere soil (*110*). These findings suggested a symbiotic relationship as well as a specific *Spirillum* relationship with grass species. Just as with *Rhizobium* of legumes, it should then be possible to improve the effectiveness of host plant/bacteria symbiosis.

Livestock on Tropical Pastures

A vast majority of livestock in the tropics graze native and natural grasslands and relatively few are given access to improved pastures. Under most conditions, an excess of herbage generally prevails for a short period of time in the rainy season, but an extreme shortage occurs in the dry season. Carrying capacity is usually based on the flush period, resulting in overstocking and overgrazing in the dry season. A rapid decline in herbage nutritive value of predominantly grass-based grazing lands imposes an additional constraint so that animals lose a high proportion of the liveweight gained during the rainy season. Cattle in the tropics have developed traits which tend to compensate for the additional climatic stress, e.g. a reduced basal metabolism which alters input-output efficiency of feed energy (*111*). Even though tropical livestock under stress conditions tend to be more efficient converters of lower quality feedstuffs than those from temperate regions, it is not yet clear to what extent these factors afford advantage to types such as the zebu.

Livestock keeping in parts of the tropics is a way of life for people and satisfies a need under present conditions. In general, the animals are not kept strictly for beef or milk, but also provide other amenities of man and his livelihood. It is only when modern agriculture and industrialization emerge that increased demands for meat, milk, and milk products arise. This forces changes in livestock keeping and prompts consideration of intensified animal and grazing land management.

Beef Production in the Tropics

Cattle with genetic potential are capable of producing remarkable liveweight daily gains on high quality pastures. In Australia, Hereford and Shorthorn steers, weighing about 250 kg/head, and grazing various pastures, made daily gains of 0.9 to 1.2 kg/head for short periods of time on young grass herbage after early rains (*112*). This compares favorably with production from temperate zone pastures. Of particular interest in this study was the daily gain of 1.2 kg/head obtained from native-type pastures duringt the flush season of growth. Tropical grasses generally are less digestible than temperate grasses, even in the young stage of growth (*113*). Steers apparently have the

Cattle grazing on improved pasture in Costa Rica. *Photo by Winrock International.*

capability, however, to handle the extra bulk needed to provide nutrient intake comparable to that of temperate species, where protein and minerals are not limiting in the young tropical grasses.

Rarely have liveweight daily gains/head exceeded 0.6 kg when steers graze over the entire season. In Puerto Rico, for example, a number of beef breeds grazing solely on fertilized grass pastures made daily gains of 0.68 kg, average of several years data. More commonly, however, an output of 0.30 to 0.40 kg per day is considered satisfactory and gains may drop to 0.10 kg or less as plants age. Plant maturity causes an increase in cell wall contents, particularly the lignin fraction, higher crude fiber, a decline in crude protein, and reduced forage intake. All of these lead to adverse animal effects causing them to lose weight unless provided supplements. An adequate supply of high quality feed throughout the year is a primary basis for increasing animal performance. The target areas for increasing beef production in the tropics are reproduction and growth rate. A serious constraint in the soil-plant-animal continuum is the shortage of feed supply during the dry season. Thus, increased attention must be given to a year-around feeding system.

The existing vegetation in native and naturalized grazing lands will never support a high level of animal performance nor production per unit of land resource. The basis for increased production and improved animal efficiency is adequate herbage nutrition through introduction and fertilization of improved legume and grass species or supplemental feeding. Additional areas of naturalized grazing lands do not provide an alternative for improved animal performance.

Naturalized grazing lands for beef cattle, however, will continue to occupy a high percentage of the land resources in the lowland tropics for some time to come. A first step in the improvement of animal output could be providing a mineral supplement. For example, in the Eastern Plains of Colombia, local cattle grazing native grasslands received a base supplement of salt, bone meal, and trace minerals (*30*). After 280 days, their average rate of gain exceeded by 50 kg/head that of animals not on supplement. This practice did not specifically alleviate the problem of feed shortage in the dry season, but gave the animals an advantage going into the stress period. Feed supplements (protein, energy, and minerals) should also be considered as alternatives in the feeding system, including conserved forage crops (*in situ*, hay, silage, etc.) and cellulosic byproducts. Nonprotein nitrogen provides a worthwhile supplement when used with locally available energy source carriers.

A consideration which holds merit under some circumstances is that of providing a supplement to enhance compensatory gains, e.g. cattle of West Africa which are raised in the tsetse fly-free regions south of the Sahara and then driven by foot for market in the south. On reaching the market site, they have dropped to a subsistence weight. Presently, there is little demand for fattened animals and no premium is paid for those in better physical condition. When consumer preference orders a higher quality product, a system of penned feeding of locally grown fertilized grass or legume, or grazing on intensively managed pastures should be given consideration. Even though the market area lies within the tsetse fly-infested region, zebu steers on improved Giant Cynodon in Nigeria gained up to 0.68 kg/head/day without protection against trypanosomiasis (*17*). Cattle driven from the north should gain double or more than this amount on a highly nutritive diet.

It is beyond the scope of this discussion to review data to substantiate the alternatives which might complement naturalized grazing lands. Their economical advantages always pose a problem and can only be resolved when the consumer demands more and higher quality beef.

Dairy Production on Tropical Pastures

The nutrient requirements of lactating cows exceed that of beef cattle and for high milk production they need high quality feedstuff. The amount of feed to produce one kg of live-

weight gain per day is equal to that needed to produce 8 to 9 kg of milk per day. Since herbage quality of tropical pastures is generally low, productivity of lactating dairy cows on a sole diet of such pastures is much less satisfactory than that of beef cattle. A compilation of milk production records from various parts of the tropics and subtropics showed yields varying from 6.5 to 15.0 kg/cow/day; the increased yields came from regions of the higher latitudes and elevations (*114*).

The main factor limiting milk production on well-fertilized tropical pastures is probably low intake of digestible energy. Jersey cows grazing fertilized pastures of Setaria and Rhodes grass in Australia produced 68.2 percent as much milk as those penned and fed alfalfa hay (*115*). Animals grazing 3-week regrowth of Setaria gave higher FCM yields (7.0 kg/cow/day) than those grazing 5-week old Setaria (6.3 kg/cow/day). Transferrring animals from a supplemented diet to sole grass pastures caused a notable decline in milk production. Comparable results occurred in another experiment, using identical twins (*116*). Cows grazing Glycine-kikuyu pasture produced about one-half the quantity of milk as those fed alfalfa plus concentrate (about 10.5 kg/cow/day and 21.5 kg, respectively, at the beginning of the trial). When moved to the legume-grass pasture, milk yields diminished by 0.4 to 0.5 kg/week, reaching a plateau between 4.5 to 6.8 kg/animal/day. In both experiments the animals gained weight over the trial period.

Fertilized Pangola grass pastures in Queensland have consistently produced higher milk yields from grazing cows than other tropical grass species (*117*). Superiority of this species comes from the increased intake of digestible energy and is probably related to the high soluble carbohydrate content in Pangola herbage (*118*). High intake of *Lablab purpureus* kept milk production of Jersey cows grazing solid stands of this legume above 10 kg/cow/day as compared to average yields below 7.0/cow on Setaria and Rhodes grass (*115*). In contrast, cows grazing Siratro and Greenleaf Desmodium gave yields of 7.7 kg/cow/day as compared to fertilized Pangola which produced 9.0 kg. As noted previously, animals grazing these two large-leafed legumes had difficulty harvesting sufficient herbage to satisy their nutritional requirements. Milk yields from Jersey cows on *Trifolium semipilosun* in Queensland averaged 16 kg/cow/day over an extended time, probably due to increased intake and higher digestibility of the more dense herbage of this compact legume (*114*).

At Ibadan, Nigeria (*119*) the milk production of White Fulani cows did not vary significantly (about 5.5 kg/head/day FCM) when grazed on different mixtures of Giant Cynodon, elephant grass, and guinea grass in mixtures with centro. Slight increases occurred when centro comprised 20 percent or more of the cover. Production declined as plants aged but daily yields and liveweight gains indicated that nutrient supplies were in excess of the genetic potential of the animals to produce milk. Despite the prevalence of tsetse fly in this area, animals were not treated for the parasite and maintained vitality when provided with an adequate and nutritive diet. At the Shika Experiment Station in Northern Nigeria, White Fulani cows on fertilized Pangola pastures averaged 5.8 kg/head/day and cross-bred Friesians 7.5 kg when fed 1.0 kg of concentrate (*120*).

Milk production of Holstein cows on intensively managed guinea, Pangola, Giant Cynodon and elephant grass pastures was determined by researchers in Puerto Rico (*40*). Pastures which received one ton/ha of 15-5-10 fertilizer were grazed in rotation — 3 days of grazing followed by 27 days of rest.

Cows remained on pasture and could graze both day and night. They received no supplement. Older cows produced about 11 kg/head/day during the first 2 years of study, but younger animals raised on grass mixtures produced 12.7 and 13.9 kg, respectively, during the latter 2 years of study. When fed 0.45 kg. of 20 percent protein concentrate per 1, 2, 3, and 4 kg of milk, daily production averaged 16.5, 17.5, 17.2, and 14.0 kg of milk per cow.

Increased output in Puerto Rico probably resulted from the use of high quality Holstein cows and their intensive management, more even distribution of rainfall, and the reduced grazing time on rotated pastures as compared to studies discussed above. An important practice was that of shortening the period of grazing which provided more nutritious herbage. This was also demonstrated in the Philippines (*121*) where reducing the grazing cycle of lactating cows on elephant, guinea, and pará to a 10-day cycle improved milk yields per cow and per hectare. When rotationally grazed at

intervals of 20 to 30 days, the grasses contained sufficient crude protein for maintenance and production of about 10 kg of milk daily, but TDN content limited production to about 5 kg daily.

Most studies of dairy production on improved pastures have been carried out in the subtropics or at higher elevations and largely with European breeds. Much of the milk and milk products in the tropics, however, comes from cross-bred and unimproved cows on native or naturalized grasslands. Although their genetic potential is restricted, milk yields of such animals can be increased to some extent by pasture improvement. The demand for milk and milk products will continue to increase as economies expand. Around urban centers this supply will undoubtedly come from intensively managed dairy operations highly dependent on concentrate feeding. Improved pastures under appropriate management practices could substantially reduce the need for high levels of concentrate feeding but additional research is needed regarding the soil-plant-animal relationships as related to dairy production in the tropics.

Water Buffalo Production in the Tropics

The water buffalo is semi-aquatic in its natural habitat but has a remarkable capacity to adapt to adverse conditions. It has long been used for draft, meat, and milk in parts of Asia, where little religious sentiment exists against eating meat from this animal. Recent importations into Brazil indicate their potential in areas subjected to flooding (*31*)

Buffalo advocates are quick to expound that this type of animal eats a greater variety of roughage and fodder than do cattle. For this reason they are considered more efficient milk producers in areas where concentrate feeds are not abundant and relatively cheap.

A number of studies have shown that buffaloes fed elephant grass, wheat straw, oat hay, rice straw, bulrush millet and berseem clover (*Trifolium alexandrinum* L.) digested a higher percentage of the proximate constituents, energy, organic matter, and cellulose than cattle. Other data indicated similar digestibilities of dry matter, organic matter, and most proximate constituents (*122*). A study in the Philippines revealed that intake of dry matter by buffaloes dropped below that of cattle, which probably accounted for the 3 to 4 percent higher herbage digestibility during the wet season (*123*). In the dry season they selected the leafier portions of elephant grass but this was not reflected in higher digestion coefficients. If cattle were restricted to the same intake as buffaloes, it is likely that no difference in digestibility would occur.

Additional studies are needed to compare the traits of buffalo and cattle under varying conditions. No doubt the buffalo will continue to be used in Asian countries for years and their value in other countries is worth exploring.

Sheep and Goat Production in the Tropics

Sheep are maintained in the tropics largely for meat purposes but also for skins, milk, manure, and hair. In warm climates with seasonal food scarcity, they have developed compensating fat reserves on or around the tail and are able to lose body heat by their hairy coat, long legs and enlarged tail, ears, and dewlap. Practically all tropical sheep are maintained on unimproved grazing lands and vegetation in wastelands. They are more selective in grazing than cattle and usually feed on the finer-type grasses and a wide variety of low-growing vegetation. Lambs respond to higher quality feed, showing an increase in size and production of body fat, but this does little to improve meat quality (*124*).

Goats are kept in the tropics, mainly as meat producers in regions where other types of livestock do not thrive or have difficulty in subsisting. They are unsurpassed in ability to fend for themselves, to consume a wide variety of edible materials and to browse almost any kind of low-growing vegetation. Goats roam widely and gather herbage overlooked by cattle, grass too short for cattle, and coarse material not accepted by sheep. In many areas the excessive goat population has led to devastation of vegetation, causing severe soil erosion. Still, they provide the basic meat supply under conditions considered too harsh for other types of livestock, e.g. the tsetse fly regions of central and west Africa (*124*). In some parts of the tropics efforts have been made to upgrade both sheep and goats by crossbreeding with exotic types. Little has been attempted in terms of improved grazing lands, and it is doubtful that priority will be given to this practice in the near future.

Strategies to Obtain Potentials

The potential for improvement of native and naturalized grazing lands as well as increasing production of pastures with cultivated grass and legume species is well documented. It has been aptly demonstrated that implementation of improved practices, along with appropriate animal management and judicious managerial skill, will measurably increase animal output per individual and per unit of land surface.

Translation of technology — An obvious urgency exists for translation of this technology into applicable forms suitable for the livestock keeper. This may be more difficult to achieve, however, than continuation of presently organized research. Putting results of animal research into practice adds another dimension to the already complex soil-plant-animal relationships. The commonly used extension techniques of distributing publications, holding field days on experimental stations or demonstration sites, and conducting on-farm scientist-planned research have not been too fruitful, even with agriculturists who might be classified as early adopters. Use of livestock farmer demonstrations with simplified designs of comparing treatments such as improved versus native grasses, weed control versus no weed control, or fertilizer versus no fertilizer are not generally effective in bringing about changes.

The lack of traditional farm responses and adoption of technological innovations is not unique to improved pasture development, but is an issue confronting other agricultural disciplines. That benefits of the so-called "Green Revolution" have favored the larger, more innovative agriculturists is well recognized. The transfer of technology downward from researchers, through innovators and early adopters, to the small agriculturist has not been altogether successful. After all, it is the farmer's decision as to what changes can be made, based on his resources, and not that of the extension agent or the researcher. They can only provide alternatives. A more dynamic approach in motivating farmers, especially those with limited resources, might be the establishment of a base line operation as determined by appropriate surveys of prevailing conditions. This can be accomplished by trained enumerators who have gained the confidence of local people. During this time, the more pertinent problems would be highlighted and alternative solutions discussed. In this way, cooperative research could be developed to involve the farmer in the planning stages, conducting of experiments, and evaluating of results.

This model does not replace supportive research of scientists trained in specialized disciplines. In fact, an integrated and interdisciplinary team effort is an essential requisite of the proposal. Perhaps this plan of operational research, or modifications to fit localized situations, more readily fits the food and field crop components of farming systems rather than the more expansive and expensive plant and animal systems. There is a great need, however, for innovative schemes to move research into the hands of the livestock farmer. To be successful they will require a redirection of policy making and probably national government intervention in some instances.

Plant breeding of tropical pasture species — Perhaps the most readily accepted innovation of livestock keepers has been the interest in new plant introductions. This was vividly demonstrated by the rapid and widespread use of Pangola grass during the late 1950's and early 1960's. More recently, a flurry of interest has been prompted in the new grass and legume cultivars developed by Australian researchers. Unfortunately, a number of cattlemen have become somewhat disillusioned in their use, since additional inputs are needed to realize the full genetic potential of superior types.

Grass and legume breeders are thus challenged to select and create cultivars more efficient in utilization of soil or applied nutrients and more nutritious for the grazing or pen (lot) fed animals. Relatively few plant breeders are engaged in the development of improved types of tropical pasture and forage crops as compared to temperate species and to field and food crops. Most of the tropical forage crop breeders are located in the subtropics of Australia (*9*, *22*), with limited programs in the highlands of Kenya (*20*), the lowlands of Nigeria (*17*), Colombia (*18*), the Philippines (personal communication), the subtropical environments of Georgia (*16*), and Florida (*110*).

In Australia, a commendable effort was put into the collection, introduction, and evaluation of tropical legumes which resulted in the release of several productive cultivars after ap-

plication of mass selection techniques. Siratro was developed by hybridization of selections introduced from tropical America. In the legume breeding program attention is devoted to persistency, shortened internodes, increased nodal rooting, and disease resistance of decumbent and trailing types such as Desmodium, Siratro, centro and Glycine; reduced mimosine content and more compact growing habit of Leucaena; adaptation of Glycine to different soil types; more vigorous and productive cultivars of Townsville stylo; creeping rooted habit of alfalfa; modified canopy of large-leafed legume types; increased forage density at all stage of plant growth, especially in the upper strata of accumulated biomass; more uniform flowering and seed development, as well as increased seed yield; extended growing season; improved associative ability with grasses; frost and drought tolerance; and intra- and interspecific hybridizations (*9*, *22*).

Legume breeding at the International Center of Tropical Agriculture (CIAT) in Colombia involves selection among ecotypes of *Stylosanthes* species, *Desmodium intortum* and inter-specific hybrids of *Centrosema Brasilianum* Benth. x *C. virginianum* (*18*). Progenies of the interspecific cross possess greater stolon development and higher disease resistance than *C. pubescens*. The improved stoloniferous characteristic should greatly enhance resistance to trampling of grazing animals and improve plant persistency.

Legume breeders work closely with microbiologists in screening for more efficient strains of *Rhizobia*, more effective nodulation, and higher rates of nitrogen fixation. Rhizobial strains are usually selected under sterile laboratory conditions at pH 6 to 7. Consideration should be given to selection and evaluation in unsterilized soil of pH 4 to 5. If the *Rhizobium* is unable to compete with native strains in the acidic soils where legumes are grown, then the selection of elite rhizobial strains hardly seems warranted.

Tropical legumes are often considered elusive and difficult to manage in combination with grasses. These implications arise mainly because of insufficient information regarding the legume potential and responses to an array of management practices and means of exploitation. The development of superior cultivars provides an alternative for pasture improvement but additional agronomic and animal evaluations are needed under regional and local conditions. If it were possible to apply the resources (funding, time and experimental effort) to any one of the promising tropical legumes as has been expended on the improvement and management of alfalfa, there is no doubt that equally spectacular advances could be made.

Tropical grass improvement comprises a significant portion of the pasture program in Australia (*9*, *125*). A number of introduced ecotypes have been commercialized in several grass species, such as buffel, guinea, *Paspalum* species, Rhodes and Setaria. Investigations of herbage quality were given high priority, finding a range up to 17 percent in organic matter digestibility among species, but less dramatic differences of 3 to 5 units within species (*126*).

Grass breeding is also being carried out in Kenya (*20*), where named cultivars of guinea, Setaria and Rhodes have been released. Seeds are produced commercially for use within the country and for export.

In Georgia dry matter digestibility of *Cynodon dactylon* ranged from 40.3 to 64.7 percent in 148 selections and F_1 hybrids, with heritability varying from 0.27 to 0.69. This indicated a potential for improvement in this characteristic through breeding and selection. One hybrid with attractive agronomic characteristics was found to be 12 percent more digestible than Coastal Bermuda grass. In feeding trials, it gave 30 percent higher daily gains and required 20 percent less dry matter per pound of liveweight gain than Coastal when both were cut at comparable stages of growth. Steers on this hybrid, named Coastcross-1, produced average daily gains of 0.74 kg/head as compared to 0.67 for Coastal. When accumulated herbage was cut in a young stage, dehydrated, pelleted, and fed to steers average daily gains were 1.05 and .85 kg/head for Coastcross-1 and Coastal, respectively (*13*). In another study grinding and pelleting *Cynodon* also resulted in higher herbage intake and milk production as compared to hay fed *ad libitum* (*127*).

In vitro digestibility varied among 158 accessions of guinea grass in Georgia (*13*), ranging from 41 to 72 percent. This variation provides an opportunity for selection of genotypes with improved herbage quality.

Apomixis in tropical grasses — Most guinea grass cultivars and selections are tetraploids and apomictic (a form of vegetative reproduction). Additional variability could be released by crossing apomicts with sexual forms. Most guinea grass populations contain small percentages of sexual plants (*6, 13*). They are usually diploids and crosses made with tetraploids, giving rise to sterile triploids. Use of colchicine to double the chromosome number of diploids should result in fertile tetraploids. After crossing these with apomictic tetraploids, obligate apomicts should appear among segregating progenies, permitting selection and fixation of superior genotypes. Diploid sexual types were found in populations of bahia grass (*128*) and buffel grass (*129*), allowing hybridization with apomictic forms and selecting of new cultivars.

Herbage digestibility — Animal productivity is the result of feed intake, digestibility percentage, and utilization efficiency of absorbed nutrients (*130*). Their relationships are not fully understood and several other factors appear to be involved, e.g. rate of passage of ingested feed through the digestive tract, differences in cell wall content, lignin and fiber structure, percentage of water soluble carbohydrates, density of consumed herbage, crude protein, digestible energy and leafiness (*99, 126, 131*). Criteria in selecting for nutritive value are difficult to elucidate. Furthermore, use of animal feeding trails are expensive and impractical in view of the many combinations of species and cultivars which could be tested under different agronomic and grazing practices.

In vitro techniques — *In vitro* digestibility (*132*) provides the animal nutritionist and plant breeder with a powerful tool in the assessment of tropical grasses and legumes. The procedure is rapid and can be routinely performed on a large number of samples (*131, 132, 133*). Predictions of herbage quality can be made since data are closely correlated with *in vivo* digestibility. For example in the development of Coastcross-1 Bermuda grass, a 12 percent advantage in digestibility was predicted from analysis of parents prior to hybridization (*13*). *In vitro* analysis can be utilized at any stage in a pasture and forage crop improvement program, from assessment of introductions to the release of new cultivars. It also has application to various agronomic and animal management practices.

Leafiness as a criterion for selection — Plant breeders and pasture agronomists have used leafiness as a selection index in the improvement of herbage quality of grasses, but there is controversy regarding its direct relationship to digestibility (*134*). The influence of leafiness on digestibility varies with species and depends somewhat on plant age. In young plants, digestibility of leaves and stems differs little, if any. As plants mature with seasonal development, stems become more highly lignified and less digestible than leaves, especially taller growing plant types. Several techniques might be utilized to offset this seasonality effect: (a) selecting types with a longer growing season; (b) use of non-flowering types, possibly making selections in one region for use in another region; (c) modification of plant structure, i.e. selecting compact types with greater bulk density which increases intake per bite of the grazing animal (*114*); and (d) genetic engineering.

In Georgia, the incorporation of a dwarf gene into Tift 23 pearl (bulrush) millet increased leaf percentage from 53.7 to 80.6 (*128*). When near isogenic lines, except for dwarfness, were cut in the boot stage, dehydrated, and fed to heifers dry matter digestibility of the more leafy type averaged 59.7 percent as compared to 55.8 percent of the normal type. Furthermore, the heifers consumed 20 percent more herbage of the dwarf and gained 50 percent faster. Steers grazing the two forages ingested a higher quantity of the dwarf millet and showed 20 percent increased liveweight gains. Total herbage yields of the dwarf were less, but beef production per unit of land area equaled that of the tall cultivar.

Crosses between species — Inter-specific hybridization provides another alternative to improve herbage quality. *In vitro* digestibility of pearl millet exceeds that of elephant grass, but it is an annual and yields less forage. Crosses between the two species produce infertile progenies. Perennial types appear, however, which have digestibility equal to millet and yield potential equal to elephant grass. Importance of selecting parental types in making crosses was demonstrated by studies carried out in Nigeria (*17*). F_1 hybrids derived from crosses using pearl millet from southeastern U.S.A. produced low forage yields and did not perennate. A Nigerian pearl millet crossed with local

selections of elephant grass gave hybrids of superior performance. *In vitro* digestibility of the better hybrids averaged 63.9 percent compared to 59.6 percent in the parental elephant grasses. Zebu heifers grazing pastures of the *Pennisetum* hybrid and elephant grass showed daily liveweight gains of 0.36 and 0.27 kg/head and daily dry matter intake of 3.1 and 2.3 kg/100 kg of body weight, respectively. Utilization of the F_1 hybrids under rotational grazing surpassed that of elephant grass, 52 and 38 percent, respectively. Being a triploid, the hybrid must be propagated vegetatively, which is also the practice in elephant grass. By selecting millet and elephant grass parents with corresponding flowering dates and planting them in alternate rows F_1 seeds were harvested from the millet parent. This should be feasible on a commercial basis.

Forage conservation and supplementary feeding — The tropical livestock keeper must contend with an inherently lower quality forage than his temperate zone counterpart, there being about 13 percent digestibility difference between tropical and temperate grasses (*135*). This difference results primarily from the higher temperature effect on increased cell wall content in tropical species (*136*). The greater proportion of cell wall reduces herbage intake and lowers animal performance because of insufficient digestible energy. Young tropical grasses usually contain enough protein and minerals to meet animal requirements. As plants age, the nitrogen content drastically declines and usually drops below the critical level of 7 to 8 percent of crude protein considered minimal for weight maintenance.

During periods of scarcity, improvement of animal performance can be achieved by the following measures:

1. Conserved forage as *in situ* grazing, hay and silage. Nitrogen applied to grass pastures prior to the onset of the dry season has been used as a means of sustaining crude protein of accumulated forage. Little or no benefit is derived from this practice in the humid tropics, since mature herbage left in the field continues to lose its nutritive value. Some advantage has been reported in the cooler subtropics (*137*).

High rainfall and humid conditions during the growing season in many regions of the tropics are not conducive to haymaking. With adequate facilities, however, good quality hay of certain species can be obtained when cuttings are made at the end of the wet season. Drying equipment would, of course, permit conservation of hay during flush periods when herbage quality is high.

Silage made from tropical pasture species does not compare favorably with that of temperate species (*138*). Tropical grasses are generally coarser and more stemmy, higher in crude fiber, lower in soluble carbohydrates, and higher in ratio of structural to nonstructural carbohydrates. Choice of species such as guinea grass, elephant, maize, sorghum, and pearl millet, along with harvests at an appropriate growth stage, care in chopping and packing would improve silage quality.

2. Feeding of crop residues, especially of leguminous species, and use of industrial byproducts or protein supplements such as urea provide other feed alternatives but must be critically viewed from an economic standpoint.

3. Drought-tolerant leguminous species can be established for ration grazing and supplemental feed.

4. Irrigation of intensively managed pastures and supplemental fertilized grasses could be considered if cost benefits were found to be favorable.

Strategies for the improvement of tropical and subtropical grazing lands depend primarily on the operational level of the livestock farmer and his economic incentives. Other factors to be considered include type of grazing land and species components, moisture regime and distribution, soil nutrient reserves, availability and use of applied fertilizers, type of livestock operation and genetic potential of animals.

Resources and Priorities

The problems of grazing land improvement are not only agricultural but also human and economic. Technical and scientific knowledge of pasture and forage crops is available in limited areas of the tropics. They need to be extended, but most of all emphasis must be given to the application of findings suited to people who have little or no capital and seldom have access to tools other than the hoe and cutlass as well as to the large cattleman. This will demand an increase in human resources in terms of trained scientists, field and laboratory tech-

nicians, and livestock managers.

Responsive grass and legume species and cultivars are presently available and more will be forthcoming from on-going and new plant breeding programs. Full expression of the genetic potential of pasture and forage plants depends on the application of appropriate management practices. Phosphorus is critical for growth, development, and high yields of legumes. Its availability in large quantities and at beneficial cost returns should receive high priority. This will require additional exploration and exploitation of natural deposits, innovative research of mycorrhizal relationships with roots of legume species in the uptake of phosphorus, and search for types of both organisms which are more efficient in phosphorus utilization. At the same time, additional attention should focus on the effects of other plant and animal nutrient relationships.

Expansion of cropland agriculture usually infringes on grazing lands as well as semi-forested areas which contain grasses and legumes. This continuously reduces the germplasm pool of potentially valuable pasture and forage crops species. An urgency prevails for immediate exploration, collection, and evaluation of genetic materials. Most agricultural experiment stations and government livestock farms maintain grass and legume introduction gardens, some of which are well organized but others are a jungle of intermixed accessions. A few plant introduction stations maintain seed supplies of a limited number of species and selections. Procurement of breeding stocks is difficult, however, and frequently their origin and true identity are unknown or questionable. A need exists for establishment of regional centers for the assembly, characterization, maintenance, and distribution of seed stocks. These centers could provide leadership in organizing and standardizing testing of promising materials. Such information would supplement and complement tropical grass and legume breeding programs.

Low quality forage and inadequate feedstuffs during the dry season impose serious constraints on effective and efficient animal output. Research on year-round feeding systems is needed with attention given to integration of improved pasture practices into native and naturalized grazing lands; selection of herbage species to extend the grazing period; the continued search for and assessment of legumes to provide supplemental sown pastures; and additional studies of conserved herbage, concentrates, farm cellulosic products, and industrial wastes as maintenance rations. These studies should be formulated and conducted by interdisciplinary teams, and emphasis should be placed on cost-benefit ratios.

Intensive research should be aimed toward a better understanding of the nutritive value of tropical forages as well as elucidation of suitable agronomic and pasture management practices for maintaining herbage quality over a period of time. Precise knowledge of the nutrient requirements of tropical livestock on pasture is needed for optimum performance. Estimates of *in vitro* and *in vivo* digestibilities using forages of comparable physiological growth should receive attention. Satisfactory feeding standards which apply to tropical conditions are not available, making it necessary to utilize and revise those prepared for temperate zones. Research should be encouraged which leads to the development and formulation of feeding tables for the tropics.

Lack of seeds imposes a serious constraint on the development of improved pastures in the tropics and subtropics. Seeds of cultivated pasture and forage grasses and legumes are produced commercially in Australia and to a limited extent in Kenya. In other countries seeds of local types may be hand-harvested but viability is low. Germination of grasses may vary between 0.5 and 5.0 percent while some legumes may approach 50 percent. The demand for high quality seeds will accompany an expanded and intensified animal industry. Basic information related to seed production must precede this development. The present selections, introductions, and cultivars must be assessed for uniformity of seed formation and maturity or new cultivars may have to be developed. Research into cultural and management aspects along with location of suitable environments for seed production will be necessary before a viable seed industry can be established, as has been accomplished in Australia. Seed production and processing techniques and procedures are being evaluated at CIAT in Colombia, but need to be expanded in national programs. Information from temperate regions pertaining to harvesting, processing, storing, and handling should have application, but further studies are needed in tropical environments. Seed production is a specialized enter-

prise so that a cadre of knowledgeable growers will need to be organized.

Integration of arable agriculture and animal production in some regions of the tropics must go beyond the relocation of people on newly cleared lands, and provision should be made to obtain farming equipment and livestock. It requires a modification of the socio-economic structure and a change in the way of life of those who, by heritage, are pastorialists or agriculturists. For those who are small farmers, but dependent on animals for power and part of their livelihood, a different approach will be needed. Only time and gradual changes in life-styles will bring about improvements. The pasture agronomist and animal scientist can contribute through research applied to the use of forages and feedstuffs in the development of alternative components of farming systems. If soil fertility is to be maintained in mixed agriculture, large quantities of herbage must be accumulated and plant nutrients incorporated during periods of fallow. Studies are needed on the use of livestock for recycling of nutrients and on tillage equipment for handling vegetational cover and root residues. Long-term arable cropping and animal rotational trials must be carried out by using cash and food crops, improved grasses and legumes, and animals having the genetic potential to respond to improved practices. Improvement of indigenous livestock by cross-breeding is necessary to transform the existing marginally economical animal-keeping practice into a well-managed profitable industry capable of not only meeting the area animal protein requirements but also potentially able to generate surpluses for export and development of related industries.

Summary

Use of cultivated grass and legume species and cultivars and implementation of agronomic practices, along with appropriate animal management and judicious managerial skills could measurably increase animal production in the tropics and subtropics.

Grass species comprise the predominant vegetation in improved pastures, native, and naturalized grazing lands. Legumes seldom make a significant contribution, except under systems of judicious management. The more commonly used cultivated grasses, many of which also occur naturally in some regions, include *Panicum maximum*, *Digitaria decumbens*, *Cynodon dactylon*, *Melinis minutiflora*, *Brachiaria mutica*, *Paspalum notatum*, *Hyparrhenia rufa*, *Cenchrus ciliaris*, *Pennisetum purpureum*, *P. clandestinum*, and *Chloris gayana*. The legumes used in improved pastures are *Centrosema pubescens*, *Stylosanthes humilis*, *S. guianensis*, *Pueraria phaseoloides*, *Desmodium intortum*, *D. uncinatum*, *Glycine wightii*, *Macroptilium atropurpureum*, and *Leucaena leucocephala*.

Most of the cultivated forms were selected as locally superior ecotypes, or were derived after mass selection among promising introductions. Relatively few cultivars have been developed by hybridization and selection among segregating progenies.

Many of the cultivated grasses and legumes comprise a broad germplasm base and are widely adapted over a spectrum of tropical and subtropical conditions. Some are recognized as being better adapted to more moist or more dry conditions and to higher and lower elevations. The zones where a potential exists for improved pasture development, and thus increased livestock production, include the wet equatorial and monsoonal areas and parts of the humid subtropics. About 60 percent of the earth's cattle population and 50 percent of the sheep and goats are found in the tropics and subtropics. They produce approximately one-third of the earth's total meat supply and one-sixth of the dairy products.

Some species of grass when adequately fertilized, particularly with nitrogen, and intensively managed produce more than 50 ton/ha of dry matter annually under cutting conditions. Forage harvested from one hectare of elephant grass in Puerto Rico was sufficient to maintain about 17 young beef animals when the forage was cut and fed daily, producing about 2420 kg/ha of liveweight gain. Grazing intensively managed pastures of elephant, guinea, pangola, and Giant Cynodon gave liveweight gains above 1400 kg/ha. Increased levels of nitrogen fertilizer boosted forage yields and permitted higher liveweight gains per hectare.

High fertilizer inputs and the related intensive management practices are not within the reach of most tropical livestock keepers. An alternative for improvement of grazing lands is that of oversowing legumes such as *Stylosanthes* species in regions of adaptation. In Australia, the combination of oversown Townsville stylo

and phosphate-base fertilizer gave a six-fold increase in beef gains/ha and almost doubled liveweight gain/head as compared to grass alone. The substitution of legume for native grass resulted in a linear, progressive improvement in liveweight gain, permitting gains during the dry season as compared to weight loss of animals on grass alone.

Studies of improved pastures comprised of grass-legume mixtures in Australia showed that beef liveweight gains increased proportionately with the percentage of legume component. With 30 percent legume, annual beef gains were less than 500 kg/ha as compared to over 1100 kg/ha obtained from Pangola grass receiving 450 kg of applied nitrogen.

Adding legumes to an improved pasture provides nitrogen for the associated grass, increases the crude protein in herbage available for grazing, and extends grazing into the dry season. For proper nodulation most tropical legumes require a cow-pea rhizobial type bacteria which produces an alkaline endproduct, as contrasted to the rhizobia of temperate legumes which produce an acidic endproduct. Tropical legumes perform well in acidic soils and only need limestone under certain conditions. Some tropical legumes require a specific type of *Rhizobium* for effective and efficient nitrogen fixation. The total nitrogen fixed by certain legumes exceeds 550 kg/ha, which is equal to that of temperate species.

Outstanding features of herbage in a legume-grass pasture are the constancy of nitrogen content of the legume component and the sustained dry matter digestibility of the mature legume forage. The legume fraction increases total dry matter intake by animals, enhances beef and milk production, and improves breeding performance as shown by increased conception rate and reduced calf mortality.

Nitrogen fixation of micro-organisms associated with the roots of many tropical grasses has far-reaching implication in the development of forage-livestock feeding systems. Wide variation occurs among grasses in nitrogen fixed by the associated organisms but estimates up to 1.5 gm/ha daily have been made for Pangola and bahia grasses.

A vast majority of livestock in the tropics graze native and natural grasslands and relatively few have access to improved pastures. Beef cattle with genetic potential are capable of making daily gains up to 1.2 kg/head on fresh growth of grass after early rains. Forage quality declines rapidly with age, however, so that animal output drops and weight loss frequently occurs during the stress of the dry season. Milk production of dairy-type cows on intensively managed tropical pastures can be maintained at about 10 kg/head/day without supplementation. In general, however, yields of one-half this amount are more commonly encountered and production of the dual-purpose tropical-type cow usually does not exceed 1.0 kg/day.

The potential for pasture improvement and increased animal output in the tropics and subtropics has been demonstrated experimentally and confirmed under farm conditions in some instances. An urgency exists for translation of this technology into a form which has wider application. This will require modification of on-farm studies to involve the livestock keeper in planning, executing, and interpreting results of research and demonstrations.

An integrated approach is highly desirable with the plant breeder, pasture agronomist, animal scientist, animal nutritionist, animal breeder, and economist working with other specialist as the need arises. There is usually a curiosity about new and improved selections and cultivars of grasses and legumes. Thus the plant breeder is challenged to search for types with higher quality and more desirable traits such as a modified canopy, increased herbage density at all stages of growth, greater persistency, extended growth into the dry season, etc. He can employ *in vitro* analysis for early screening of breeding materials, thus accelerating selection of superior types. The pasture agronomist must collaborate in the testing of introductions and new cultivars in various agronomic trials and animal management practices. Of particular concern is the development of year-round feeding programs which will involve selection of grass and legume types with an extended growing season and sustained nutritive value, forage conservation, and supplementary feeding. Attention should also be given to exploitation of legumes, exploration and conservation of germplasm, a better understanding of the nutritive value of tropical forages, availability of seeds and planting material, and integration of arable agriculture and livestock keeping.

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POTENTIAL OF ARID AND SEMI-ARID RANGELANDS

for Ruminant Animal Production

THADIS W. BOX[1]

Although the arid and semi-arid rangelands of the world provide a home for millions of head of livestock and thousands of pastoralists, they have not been considered areas of high potential for development capital or research activities. They have usually attracted attention only during drought or famine when the suffering of livestock and people pricks the conscience of more fortunate people. For the most part, these areas have not been studied intensively. In many cases they have not even been properly mapped or adequately inventoried. Their ecology is poorly understood and their potential has not been measured. However, if only because of their vast area, they must be considered a major potential contributor to the world's animal protein supply.

Recently there has been a growing interest in these arid and semi-arid rangelands of the world. Developing countries are beginning to increase their activities in these drier regions primarily with the objective of increasing red meat production either for home consumption or for export (*1*). In the developed countries, arid and semi-arid lands are not only receiving demands for red meat production but are also being considered as a source for recreation, fuel, water, and other goods and services desired by the affluent society (*2*).

World concern for proper management of rangelands will likely increase. Because of continued human population growth, marginal lands will be used for the production of grain, much of which will be consumed by humans. Marginal croplands will no longer be available for livestock production; grain for feedlots will become in short supply.

A major world energy shortage will mean fewer wood substitutes for the construction industry, and, thus, more demands will be put on marginal forests. These, too, then, will be removed from land available for livestock production.

Although per capita consumption of red meat may decrease, the total need for high quality animal protein will continue to increase as the human population grows. Since there may be less land available on which to produce livestock products, it will be necessary to manage the arid and semi-arid rangelands more intensively than has been done in the past.

Productivity cannot be maintained on these lands if they are managed by using standard agronomic practices. On the contrary, the major use will continue to be for grazing by wild and domestic animals. The science of ecology forms the basis for decisions that will have to be made on these lands where management must, of necessity, operate with low inputs of capital, fossil fuel, etc. Management necessary for improved production from arid and semi-arid rangelands will have to be geared to the special conditions of these dry regions.

Some rather severe restrictions and constraints are imposed on dry lands by characteristics and factors that limit achieving the potential. In the first place, the setting under which we must try to achieve the potential is harsh. Precipitation is low. Biological productivity is erratic and related to survival rather than production. Few social or economic institutions have been developed to aid the economic growth or the potential production that rangelands can achieve. Although rangelands represent an important and neglected resource, their potential for producing red meat from ruminants will be difficult to achieve.

CLIMATIC CHARACTERISTICS

Rainfall in arid and semi-arid rangelands is low, erratic and poorly distributed — not only spatially but seasonally and yearly. Rainfall

[1] Thadis W. Box is Dean, College of Natural Resources, Utah State University, Logan, Utah 84321.

does not often come in frontal storms uniformly distributed over an area. Storms may produce adequate rainfall for plant growth on one part of the range, while on another area only a few kilometers away no rainfall occurs. This pattern contributes to rather ineffective use of moisture produced by rainfall. It often results in luxurious growth on a small segment of the range on which animals concentrate their grazing, while other areas are almost unused.

Quantity and distribution of seasonal moisture usually limit growth to one period of the year and determine the type of plants that inhabit an area. Extreme examples vary from cold desert shrubland where plant growth is related to the amount of moisture from snowmelt in early spring to tropical areas where growth is initiated by monsoonal storms occurring only a few months during the year.

Precipitation between years is also erratic; prolonged droughts are common and expected (*3*). Total amount of dry matter produced can vary 300 percent or more between years within a climatic cycle, contributing to a feast or famine forage situation. A climatic cycle is a recurring period of years in which climate fluctuates widely from the norm.

In addition to the varying and erratic rainfall, both low and high temperature extremes are common on arid rangelands. High winds and blowing dust may further contribute to the harsh climate of the arid and semi-arid rangelands of the world. Generally, the biology of an area reflects these extreme fluctuations in climate.

BIOLOGICAL CHARACTERISTICS

Biological productivity on dry rangelands is usually low and highly variable. Plants have evolved primarily for survival rather than high productivity. Modifications that have developed to allow them to survive rigorous climatic conditions are not usually associated with great production of biomass. Such special adaptations as dormancy, curling or dropping of leaves, large root-to-shoot ratios, etc., may enable plants to withstand the severe conditions of deserts, but these same plants may not produce forage as efficiently as plants growing under more moderate conditions. Not only may production be low but the evolutionary change of the plants for survival, such as protective thorns, may make plant material difficult for grazing animals to eat.

Like the plants, animals have also evolved to make the best use of arid conditions. One of their major modifications is for the conservation of water. Animal species that have survived on dry rangelands usually do well on low-quality forages but may have rather low reproduction rates, especially during dry years. The kind of animal that survives best on arid range situations may not be the same kind as desired for the human economy. For instance, traditional types of livestock may not do well on many of the arid shrublands. Cattle and sheep, in particular, find that the modified leaves, stems, and thorns are a major deterrent in feeding. Goats and camels better utilize the shrubs in the dry areas, but even they might not be as efficient in the use of shrubs as the large native ungulates that feed upon the plants. Native animals not only have developed the potential for utilizing low quality forages but also have adjusted to the variable rainfall patterns and plant production.

Plant communities have seldom evolved under continuous grazing pressures. Instead, they have developed under a system of shifting, nomadic use adapted to spotty rainfall patterns. Attempts to change the pattern of grazing use and to obtain a greater yield of animal products have often led to deterioration of the plant community and loss of the more desirable plants. Successful use of arid rangelands has seldom occurred under continuous grazing systems. The nomadic or transhumant pastoralists of Africa and Asia have developed a system of seasonal use related to the rainfall patterns that in effect establishes a rotation system of grazing (*4*). In developed countries such as the United States and Australia, this nomadic use has become refined and sophisticated. For instance, in the intermountain area of the United States, summer and winter sheep ranges may be 300 to 400 km from one another. Animals are hauled from one location to the other, but the resulting use of the land is much the same as that of nomadic pastoralists.

Not only have most rangelands developed under a pattern of seasonal use, but they have evolved under grazing and browsing by a variety of herbivores ranging from invertebrates to large browsing animals. Attempts to change the pattern of use and impose heavy continu-

ous grazing systems by a single class of domestic animals usually lead to a loss of desirable forage plants from the plant community and a general deterioration of the range.

Most rangeland ecosystems are rather delicately balanced and this balance is easily disrupted by abusive grazing. Improvement processes are extremely slow in the dry regions; once an area has been disturbed, it is slow to heal itself. Any rapid improvement may have to be encouraged with artificial means. But artificial restoration of damaged rangelands is, at best, difficult because of the rigorous climatic and biological constraints imposed upon the system.

SOCIOLOGICAL FACTORS

Arid and semi-arid rangelands typically have a low population density. Most of the people live in a few trade centers, towns, or cities; the remaining people are widely scattered, usually poorly organized, and resist attempts to control their independent life style.

Political power in range areas is concentrated in the cities. Because needs of society are perceived differently by city dwellers than pastoralists or ranchers, available public funds are more likely to be used in the population centers than in the rangeland areas.

Support facilities are usually inadequate or lacking and communication networks are primitive. Transportation may be costly, or, if roads have not been developed, modern transportation facilities may be totally lacking. Communication between individuals and groups of people is usually difficult. The ability to move products from arid and semi-arid rangelands to market is often severely restricted (*5*).

Lack of public support for projects (whether development or research) in range areas in large countries having uneven population distribution is related more to the perception of priorities by people living in the high population areas rather than the needs of arid zones (*6*). The inability of people in the range areas to make their needs known further contributes to the lack of public support for projects on rangelands.

When a small country is located entirely within an arid area, it may lack the ability to support its own development. Such countries have learned that the world community does not view its development projects as high-priority items. And since they have only arid lands, they feel that they are destined to continued poverty.

The isolation of people in arid and semi-arid range areas has tended to make them self-sufficient. They are strongly individualistic and usually tend to act on their own initiative rather than collectively. Traditional use of much of the arid rangelands has been through nomadic pastoralism. The nomadic habit is generally discouraged in developing countries, but the nomadic sector has been identified as a major factor in the economic development of some arid range countries (*7*). Although the traditional movement of people and livestock throughout shrublands usually fits the physiology of plants and the general ecology of the plant community (*8*), nomadic life may not be popular with the ruling segment of a country.

Social institutions serving the rangeland areas of the world are usually weak. Such fundamental items as health care and education are often inadequate and contribute to the continued low productivity of rangelands by limiting the number of people entering the professions that control the destiny of the range areas.

Research efforts directed toward improved land management are often scattered and poorly funded. Most countries tend to finance research projects that relate most directly to the largest number of people. Hence, research programs in the non-arid areas have the highest priorities.

In many of the Sahelian countries of Africa, not a single university graduate in range management is available to collect data. In the United States, range management research has continuously declined over the last decade and is totally inadequate for the management needs of the public lands alone (*9*).

Sociological factors are further complicated by severe economic restrictions. Arid and semi-arid rangelands offer a high risk and low returns to investment. Almost no financial institutions are geared specifically to the development and improvement of arid regions. Use of rangelands requires a unique financial structure if full development is to be achieved.

Loans for range improvement must be long term — at least two or more climatic cycles to allow time for the program to pay for itself. Repayment schedules should be adjusted to

the feast-and-famine production characteristics of rangelands. Until venture capital is available under conditions specifically designed for the arid and semi-arid range areas, little sound development can take place in these potentially productive areas.

EXTENT AND CONDITION OF ARID AND SEMI-ARID RANGELANDS

Arid and semi-arid rangelands of the world are located on all continents. They occur under various climatic regimes and numerous political and social structures. Developed market economies influence the management of the rangelands in North America and Australia. Developing countries with market economies and large amounts of rangelands occur in South America, Africa, and Southwest Asia. Rangelands in centrally planned economies occur primarily in Asia.

The red meat productivity of these lands, either present or potential, cannot be accurately estimated. In most cases, a given area of arid rangeland is used only part of the year—often during a severe stress period for the livestock. For instance, in the cold desert regions of the world, the arid rangelands are used for winter grazing. Animals are not expected to gain weight during the cold months and may actually lose weight during the period of time they are using the range. However, without the dry ranges to support the animals during the severe season, the more lush ranges where rapid gain is made could not be used.

It is difficult to estimate the condition of arid rangelands. It is even more difficult to estimate the extent to which the carrying capacity of the range could be increased if range condition improved. Even if the exact condition and carrying capacity of arid ranges were known, there is no guarantee that an increase in carrying capacity of arid rangelands would increase red meat production unless there is excess summer range or feed for keeping the animals confined in feedlots for part of their lives.

North American Rangelands

Roughly three-fourths of the arid and semi-arid rangelands of North America is grazed by domestic livestock (*10*). Grazing on the federally owned areas of the western United States (which also includes humid and subhumid mountain grazing lands) provides about 12 percent of the annual forage requirement for livestock in the 11 western states.

Opinions on the condition of these dry rangelands differ among individuals and are hotly debated. For the most part, environmentalists claim the ranges are heavily overgrazed and are deteriorating. Ranchers often contend that ranges are improving and that the current condition is better than it was a decade ago.

Techniques for measuring range conditions are imprecise at best. Estimates of conditions have been made at several times, using varying methods and for many purposes. Even though the range was viewed each time through different eyes and measured against new technology at each assessment, some major generalizations about the condition of American ranges have been made (*11*).

First, virtually all of the western range was grazed exploitatively in the late 1800's. The first settlers overestimated the carrying capacity of the arid rangelands, overstocked them, and the range deteriorated. By the beginning of the 20th century, only those lands naturally protected from livestock, e.g., without water or high mesas, were in good condition. The major range deterioration occurred about three decades after settlement. For the arid rangelands this was between 1850 and 1900.

The USDA Forest Service established regulation on grazing use in 1905. Between 1905 and 1935 National Forest rangeland improved, but productivity of other ranges continued to decline.

Little improvement was made on arid rangelands during this time. Most of the ranges managed by the Forest Service were on the more humid mountain ranges. It was during this period that grazing on the National Forests was brought under control and range management as a science began to emerge. The first range management research was published, courses began to appear in universities, and texts were developed (*18*). Isolated improvement was made on private and Indian lands where the emerging art of range management was taught and practiced (*19*).

In the next 30-year period, between 1936 and 1966, the more arid rangelands improved somewhat. This can be seen in the change in condition of the lands, mostly arid, managed

A herd of approximately 6,000 sheep grazing on ranchland in British Columbia, Canada. *FAO photo.*

by the Bureau of Land Management (BLM). Although there was little or no change in the percentage of good or excellent range, the amount of range considered to be in poor or bad condition was estimated to have declined from 58 percent in 1936 to 33 percent in 1966 (Table 1). At the same time, the fair condition range increased from 26 percent to 49 percent.

The shift from poor to fair condition on arid rangelands is best documented on the lands managed by the BLM (Table 2). The response was slow and small because most of the dry ranges were extremely depleted by excessive "free range" use at the beginning of the period, and the arid nature of the ranges does not permit a quick recovery. A move of one condition class in 30 years can be considered a successful response to management.

Data for 1972 and 1975 are not valid estimates of condition of the ranges (*20*). Few range condition and trend studies have been made during the past 10 years. Therefore, the estimates for the last two periods in Table 2 are probably only extensions of the 1966 data.

The estimates of current condition of American ranges vary, but almost all list from two-thirds to three-fourths of the range in fair or poor condition. Although the definition of condition is different in different agencies, it is safe to assume that up to three-fourths of the arid rangelands are producing less than half of the forage of which they are capable.

Estimates for potential production can be made from various discussions of the goals for range improvement. The USDA Forest Service (*21*) estimated that ranges under its control, if improved, would allow an increase in stocking from the present 11.3 million Animal Unit Months (AUM's)[1] to 16.3 million in 1980 and 20.4 million in 2020. However, their report did not deal with the arid rangelands separately from those of the humid areas. The Bureau of

[1] An "animal unit month" is equivalent to the amount of feed or forage required by one mature 1,000 lb. cow, or equivalent, for one month, as based on a daily consumption of 26 lbs. of dry matter.

Table 1 — Percentage of all Federal land in three condition classes[1].

Year	Condition class: Good or excellent	Fair	Poor or bad
	Percent		
1936[2]	16	26	58
1966[3]	18	49	33
1972[4]	18	50	32

[1] All data rounded to the nearest percentage point.

[2] Data adapted from depletion classes in Senate Document 199 (*12*). Moderate depletion was used to represent good condition; material depletion, fair condition; severe and extreme depletion, poor or bad condition.

[3] Data from Pacific Consultants (*13*).

[4] Data from Forest Report No. 19, USDA Forest Service (*14*).

Table 2. — Percentage of land administered by Bureau of Land Management in 3 condition classes

Year	Good and excellent	Fair	Poor or bad
	Percent		
1936[1]	1.5	14.3	84.2
1961[2]	16.6	53.1	30.3
1966[2]	18.9	51.6	29.5
1972[3]	17.6	50.0	32.4
1975[4]	17.0	50.0	33.0

[1] Source: Senate Document 199, 75th Congress, 2nd Session. Range condition classes were not reported as such but are inferred from percent depletion figures: Moderate depletion = good or excellent; Material depletion = fair; severe and extreme depletion = poor.
[2] Source: Pacific Consultants (*15*).
[3] Source: Forest Resource Report No. 19 (*16*). These figures include all Federal ranges and are not from the same data base as those reported above.
[4] Data from USDI Range Condition Report (*17*).

Land Management has stated that by intensive management they could improve 78 million acres of rangeland from fair and poor condition to good condition by the year 2000 (*22*). Neither of these estimates is given in terms that can be converted to livestock gain on the particular lands. Even worse, a change of production on either summer or winter range may not lead to increased livestock production overall.

Livestock production on American range could be doubled if proper management were applied (*23*), if we can assume that other forages would be developed and that new systems of ranching would evolve that would make the most efficient use of the arid rangelands.

Australia's Arid Rangelands

About three-fourths of Australia, or over 570 million hectares, is arid rangeland (*24*). This rangeland has been through a history of both overestimation and overstocking of its carrying capacity, resulting in severe degradation of the land (*25*). The ranges of Australia are still managed extensively on a low-input basis (*26*).

There has been no nationwide measurement of range condition in Australia. A method of range assessment is being developed that will allow range condition to be compared with American ranges. Although estimates of range condition are inadequate for Australia, several descriptions (*27*) indicate that most of the

ranges are in fair or poor condition. Therefore, it is reasonable to assume that livestock production could be doubled with proper management.

African and Southwestern Asian Rangelands

Estimates of range condition in most developing countries are inadequate; in many they are totally lacking. The general opinion, however, is that the arid and semi-arid rangelands of Africa and the Middle East are more severely degraded than most. Others maintain that this image is a result of an inaccurate evaluation of the drought by the popular press.

Two workshops have recently been conducted by FAO to examine the conditions of the ranges of Africa and Southwest Asia and make recommendations for their improvement (*28*). Both conferences concluded that rangelands of the area were severely degraded and in immediate need of attention. Conclusions of the first conference, an expert consultation organized by FAO and UNEP, were as follows:

1. Rangelands where water is available are badly deteriorated and in need of rehabilitation and management.

2. Deterioration has accelerated in recent years, but degradation cannot be attributed solely to drought. The major cause is that human and livestock populations simply exceeded the carrying capacity of the land.

3. Most development efforts have failed. Failure has been due to application of humid zone technology to arid areas and a lack of commitment by governments to face the special problems of arid lands.

4. More resources need to be dedicated to arid rangeland development. Of special need are increased predevelopment inventory and planning, better management and institutional organization for control of grazing on rangeland, and more participation by people actually living on the land.

5. Almost without exception governments need to strengthen the services which are responsible for range development and management.

6. Potential of rangelands cannot be reached through the application of single measures. Rather, all programs need to be considered in a systems context and then the required inputs should be applied in a logical sequence, jointly supported by the governments of the region and by international organizations.

The second conference endorsed the findings of the consultation and concluded that the problem of rangeland condition was serious, acute, and in need of immediate actions. They expanded on problems discussed by the previous conference and placed special emphasis on the need for more range personnel, more participation at the local level, and range development schemes instituted on a national level.

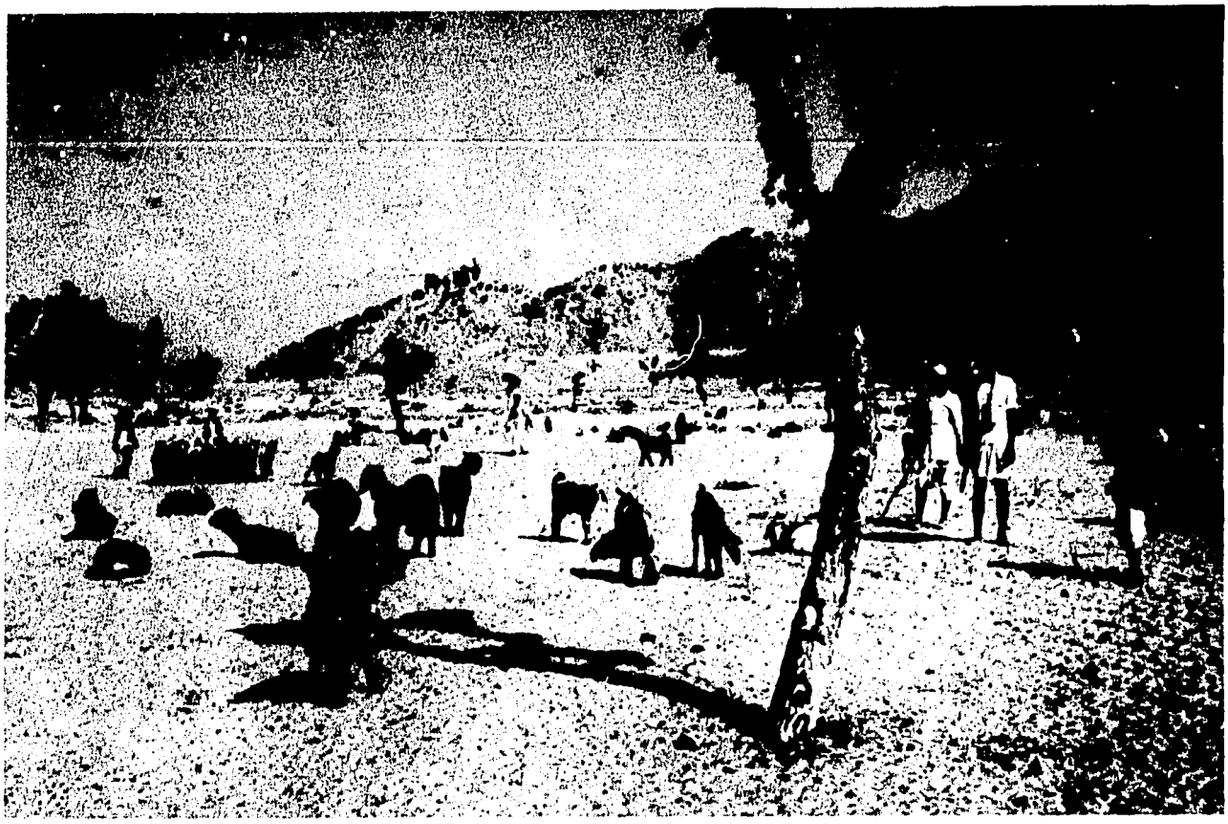
Recommendations of the second conference stressed the need for an international range organization, national and regional range improvement projects, and special aid from international donors. A recommendation that education and manpower training be given the highest priority at all levels is significant recognition that the potential of the rangelands cannot be reached unless proper management is applied.

The number of livestock using African rangelands is high: 148 million cattle, 2.1 million buffalo, 9.4 million camels, 148 million sheep, and 116 million goats (*29*). Almost all the sheep, goats, and camels use arid or semi-arid ranges for much of their grazing. A lesser, but large, number of cattle and buffalo use the arid ranges during the wet season. Unfortunately, records do not show how many AUMs are now produced from the arid and semi-arid rangelands. There appears to be no estimate of the potential of these rangelends for livestock production.

Few animals remain on any one part of the arid or semi-arid rangelands yearlong. Neither the condition of the ranges, the length of time animals graze on them, nor the total numbers of animals have been documented in most African arid rangelands. The current carrying capacity is not now known. An estimate of potential increase must be regarded simply as a guess.

Asian Arid Lands

No estimate of range condition is available for the ranges of the USSR and the Republic of China, which constitute the vast majority of the arid rangelands of Asia. However, from examination of botanical studies (*30*) and comments from people working in the area, it



Goats browsing in a desert near Jodpur, Rajasthan, India. *Photo by John W. Hibbs.*

can be assumed that the condition of these areas is similar to those discussed for Southwest Asia. For the most part they are degraded, heavily grazed; and in need of improvement.

Since an accurate assessment of range condition and productivity is not available, neither can an accurate estimate of potential be made. It is the general opinion of range scientists who have worked in or visited Asia's arid areas that the ranges can be "improved greatly."

South American Rangelands

Range conditions have not been estimated for the rangelands of most of South America in such a manner that would allow direct comparison with those of North America. However, some studies lend themselves to a broad general estimate of range conditions (*31*). Special sessions by FAO, USAID, and other international groups show that ranges in local areas are depleted and need improvement. Although no estimate of potential for improvement is available, it can be safe to assume that livestock output could be doubled or perhaps tripled, especially if the arid ranges are managed in conjunction with the subhumid rangelands.

NEED FOR PROPER MANAGEMENT DATA

One of the major shortcomings in achieving the potential productivity of rangelands is the inadequacy of the data base. Even in countries where range management is the most advanced, such as the United States and Australia, too little attention has been given to developing estimates of carrying capacity, range condition and trend, and population dynamics of wild herbivores needed for the intensive management schemes that will eventually be used.

In both the Forest Service and Bureau of Land Management, inventory data at the allotment and district level on range sites, condition classes, and wildlife populations vary from fair to totally lacking (*32*). In some cases, data needed for proper management simply do not exist. The extensiveness of the areas under stewardship and the personnel inadequacies of the agencies virtually preclude adequate inventory at present.

Fundamental knowledge of plant response to grazing is incomplete and fragmented. There are few satisfactory measures of goods and services (other than grazing) provided by rangelands. In many cases range condition and trend studies have not been conducted on the public rangelands of the United States since the mid-1960's. Carrying capacities on many allotments are yet to be determined, even though they have been managed by agencies for over 40 years. These deplorable conditions exist in a country with the world's best developed range management capabilities.

In Australia, although much of the country has been covered with broad general land classification surveys, detailed information on range conditions and carrying capacity are lacking (*33*). One of the current objectives in Australian rangeland management is to develop an assessment mechanism suitable for the extensive arid Australian rangelands. Other countries generally considered to have reasonable adequate data bases for management of rangelands include Canada and Mexico, but they, too, are in a situation similar to that of the United States or Australia. Priorities in all of the developed countries have been on placing the research and development capital and manpower training in areas of high rainfall that have an apparent higher potential for economic return, leaving the drier grazing areas of each country largely without adequate data on which to base the management.

Not only is the inventory data for proper management inadequate for most of the world's rangeland but the research information is also lacking in most areas. The largest body of range research comes from studies conducted in North America and in Australia. Almost without exception, these studies have concentrated on the problems of temperate rangelands and have worked mostly with cattle or sheep. They were based on production systems of a market economy in a developed country where investment capital is available. For the most part, research on goats, camels, buffalo, and animals other than sheep and cattle has been neglected. Research on tropical ranges lags far behind that of the temperate areas. Little has been done with research on integrating the social systems of nomadic pastoralism with range production.

Even in the developed countries, research efforts are largely inadequate (*34*). High on the list of needs for research are mechanistic descriptions of range systems in sufficient detail to allow experience in one area to be transferred to another. In the past, the problems of plant-animal interaction have been approached largely through long term grazing studies that may describe a system in a given area but may not be transferrable to another. Unfortunately, even these long term grazing studies are now being abandoned.

Research needs in developing countries are much more pressing than those in the developed countries. Priorities for range research include techniques for rapid and accurate inventory of resources (*35*). In addition to this, we need (a) research on technology transfer that would allow information available in developed countries to be applied, and (b) an understanding of tropical range systems.

The most obvious reason for inadequate range research is low level of funding. For instance, in the United States virtually all range research is done by the U.S. Department of Agriculture (primarily in the Forest Service and Agricultural Research Service) and in a few western universities. The Bureau of Land Management, the only agency with range management as its central purpose, has never had a range research arm of its own; and, while numerous state agencies conduct research on forest and wildlife management, none conducts range research purely from a livestock perspective.

A major result of the low funding level is, of course, a limited manpower resource for range research. In western states, only 61.3 scientist-man years (SMY's) are devoted to range research. This includes the Forest Service, Agricultural Research Service, and state agricultural experiment stations. By contrast there are 65.9 SMY's in forest utilization research alone and a total of 504 SMY's in all forestry research (*36*).

Australia, with one of the largest range areas in the world, has only a few dozen people working in range research and these are scattered at such widely separated locations as Deniliquin, New South Wales; Alice Springs, Northern Territory; and Perth, Western Australia.

The number of people trained to do range research in developing countries is woefully low. Almost none exists in West Africa. There are a few in most East African countries, primarily trained on USAID or FAO fellowships in the United States or Australia. There is no

university in all of Africa with a curriculum designed to train range research specialists.

Although range research scientists throughout the world are in short supply, there is an even more critical need for people trained to manage rangelands. This shortage exists in both the developed and the developing countries of the world. The United States has the longest history of range management and more institutions capable of training range management specialists. However, even in this country, the number of people managing rangelands is totally inadequate. The Bureau of Land Management and the U.S. Department of the Interior recently studied their own manpower needs through a series of state studies. The Nevada Report indicated "all districts have a severe shortage of personnel. Area managers have 2 to 3 million acres under their administration and have only 2 to 3 other employees to assist them . . . " (*37*). The lack of personnel as discussed in Nevada existed in every state. In addition, the amount of money spent on range management has declined in the United States in the preceding 10 years (*38*). In Colorado the actual dollars used for range work declined about 20 percent between 1965 and 1974. When this figure was adjusted for inflation and higher salaries, the effective reduction was about 50 percent over the 10-year period (*39*). Even greater shortages exist in other developed countries such as Canada, Mexico, and Australia. For instance, in Australia only two range management personnel are assigned to provide technical assistance for the entire state of Western Australia, an area roughly one-third as large as the United States.

Even more pressing in the developing countries is the need for technician-level training. An excellent school, turning out diploma-level range management technicians, was established in Kenya a number of years ago at Edgerton College. This program trains people to do technical range surveys and technical management but does not offer university-level work. Unfortunately, it cannot even fill the needs of Kenya alone. A number of such training centers should be established throughout the developing nations. Special emphasis should be given to getting people from the pastoral tribes into the range management training program. In far too many cases, students in range management programs, at both the graduate and the diploma levels, have come from these sedentary agricultural peoples and, once trained in range management, find it difficult to work in the harsh outposts where most of the range work exists.

PUBLIC POLICY NEEDS

The major public policy need for range management in both the developed and developing countries is a commitment by government to insure that the dry, less-productive regions of the country will receive adequate attention on a continuous basis rather than responding to drought or other crises.

In the developed countries of the world the major need appears to be an increase in the manpower for management and research, some security of tenure for people using the lands, and development capital that is especially designed for repayment under the harsh conditions of the arid and semi-arid world.

Similar needs for public policy exist in developing countries. However, the most important single public policy needed in most developing countries is establishment of a separate range management agency (*40*). Far too often the range management responsibility, if it exists at all, is buried in a ministry of agriculture, ministry of planning, ministry of tourism, or some other administrative organization without adequate contact with budget makers and people who direct the future of the country. Many believe that the establishment of proper range management agencies in developing countries with adequate authority to control and enforce grazing would be the biggest single contribution toward reaching the potential of the arid and semi-arid rangelands (FAO 1974).

CONCLUSIONS

The potential for increased ruminant production from arid and semi-arid rangeland is good. Various estimates exist as to the extent to which this can be accomplished — from doubling to tripling the current production from most of these range areas. The potential for doubling is very good if (a) an adequate inventory data base is developed, (b) personnel are made available for managing these rangelands, (c) institutions are developed to manage the land and monitor the results of that management, and (d) new and different approaches

are developed as the need for goods and services from the rangeland changes.

The direction in which range management of the world's arid and semi-arid rangelands changes in the future depends primarily upon human population growth. If population growth is stabilized, we can expect range management to develop worldwide in much the same form as exists in America today. Rangelands will probably be used more for goods and services other than meat; such items as recreation, watershed, and aesthetics will become increasingly more important.

Human population, however, will probably not be stabilized in the world community in the near future; therefore some rather major changes in range management such as the following are likely to occur:

1. Food chains will be shortened and more vegetable crops will be eaten. New crops will be developed, such as high-lysine corn, and the world cultures will gradually shift to eating plant products rather than meat.

2. Many areas now in rangeland will be converted to crop production. In the short run we may see cropland go back to grass. However, if the human population continues to grow, it will be imperative to use all land that can grow crops for the production of human food. New dryland techniques will be employed to make many of these areas productive. Total hectares of rangeland will decrease.

3. Animal protein will be produced from those areas unsuitable for crop production. This meat production may not come from the traditional livestock such as sheep and cattle. Efficiency of animals may dictate that we raise goats, camels, donkeys, antelope, rabbits, or kangaroo rats on the rangelands if we are interested in greatest efficiency of protein production. This may in turn call for changes in customs of people, their dietary habits, and their attitudes toward food.

4. Rangelands will produce a luxury crop, red meat, and also serve as major recreational and waste disposal areas.

5. Even if human population can be controlled, multiple use of rangeland resources for services in addition to red meat will be a necessity.

Use of rangelands of the future will change rapidly. The basic use will still be determined by the ecological factors of the environment. Social, political, and cultural factors will modify this ecological base. Tradition largely dictates land use, whether in Australia, East Africa, or elsewhere. The major difference is that in the developing countries of the world, the attitude of the producer is important. However, in developed and industrialized nations of the world the opinions, attitudes, and social customs of the consumer may matter more than those of the people actually on the land.

If men can properly integrate their social and political impacts of range use with the biological productivity of the land and develop new research and institutions for the management of arid and semi-arid rangelands, the potential for increased production is great. However, if the managers of the future continue business as usual, deterioration will continue and production will decrease.

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DR. R. J. BULA

Dr. R. J. Bula, research agronomist, is a native of Wisconsin and received his education at the University of Wisconsin. Positions held include Agricultural Research Service, USDA in Alaska 1953-55; and Purdue, 1955-74. Since 1974 has served as area director, Illinois-Indiana-Ohio area for ARS-USDA West Lafayette, Ind. Research emphasized studies on environmental physiology of forage species and genetic stability of improved forage varieties. Reviewed forage research in Eastern and Western European centers for ARS-USDA PL 480 project and other ARS International Programs.

DR. L. R. HUMPHREYS

Dr. L. R. Humphreys of Sydney, Australia, is Reader in Agronomy, University of Queensland. He received his B.S. and M.S. degrees at the University of Sydney and his PhD at University of Queensland. He has been engaged in tropical pasture research and education for 25 years and is the author of three books and more than 50 journal articles. He is involved in research and training projects in Northern Australia and Southeast Asia and is currently the Australian and New Zealand representative on the International Grassland Congress Continuing Committee.

DR. VICTOR L. LECHTENBERG

Dr. Victor L. Lechtenberg, associate professor of agronomy, Purdue University. Reared on a livestock farm in Northcentral Nebraska. B.S. University of Nebraska, 1967 and PhD Purdue University, 1971. Research responsibilities and interests in forage crop production, quality, and utilization with special emphasis on aspects of quality and utilization important in efficient ruminant animal production.

DR. LOY V. CROWDER

Dr. Loy V. Crowder, B.S. Berry College; M.S. University of Georgia; PhD Cornell University. Pasture specialist, Georgia Experiment Station; Director, National Pasture & Forage Program, Rockefeller Foundation and Columbia Ministry of Agriculture, 8 years; since 1963, professor, plant breeding and international agriculture, Cornell. Research emphasis on grass and legume introductions and evaluations, aspects of pasture management, forage crops breeding, feeding trials, and soil conservation. Consultant and/or visiting scientist in the Philippines, Pakistan, Nigeria, Nepal, Dominican Republic, Ecuador, Colombia, Venezuela, Chile, Brazil, Costa Rica, and Turrialba.

DR. DONALD A. HOLT

Dr. Donald A. Holt, professor of agronomy, Purdue University. B.S. & M.S. degrees, University of Illinois; PhD Purdue University, 1967. Teacher and researcher at Purdue since 1967. Primary interests in environmental physiology of crops, computer simulation of crop growth, and forage crop management. He is chairman of Pudue University Resource Policy Committee; past chairman of the School of Agriculture Graduate Counsel; and member of several important university committees. Dr. Holt teaches graduate level courses in agronomic research techniques, and environmental physiology of crops.

DR. THADIS W. BOX

Dr. Thadis W. Box, Dean, College of Natural Resources, Utah State University. B.S. at Southwest Texas State College, M.S. and PhD at Texas A & M University in range management. Taught at Utah State and Texas Tech; range research scientist at Welder Wildlife Foundation; director, International Center for Arid & Semi-arid Land Studies, Texas Tech; Special lectures and seminars in Mexico, Argentina, Australia, and India. Has held committee assignments and consultancies with USAID, USDA, USDI, FAO, National Academy of Sciences.

Winrock International Livestock Research and Training Center

R. O. Wheeler, President

E. K. Byington, Ph.D., Range Scientist
R. Dennis Child, Ph.D., Range Scientist
G. E. Cooper, Ph.D., Animal Nutritionist
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E. L. Williams, M.B.A., Program Officer
P. Woodruff, B.A., Financial Officer

Visiting Scientist:
J. P. Workman, Ph.D., Range Scientist

Consultants:
T. C. Byerly, Ph.D., Animal Scientist
R. D. Child, M.S., Livestock Specialist
H. A. Glimp, Ph.D., Animal Nutritionist
H. J. Hodgson, Ph.D., Forage Agronomist
L. J. Nygaard, Ph.D., Livestock Specialist
O. J. Scoville, Ph.D., Agricultural Economist

Winrock International Livestock Research and Training Center
Petit Jean Mountain, Morrilton, Arkansas 72110
Phone (501) 727-5435