THEMATIC BACKGROUND STUDY

# Plant Genetic Resources of Forage Crops, Pasture and Rangelands

C. Batello
R. Brinkman
L.'t Mannetje
A. Martinez
J. Suttie

## Disclaimer

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# EXECUTIVE SUMMARY

## Genetic resources of forage and grassland species

Forage genetic resources play a very important role in food security and poverty alleviation, particularly in developing countries. Grassland and forage genetic resources underwrite and support particularly Millennium Development Goals 1 and 7. Forages (herbaceous feed for herbivores) include grasses, legumes and other herbaceous species. Most forages grow in grasslands, are produced by fodder crops or are provided by food crop residues.

Grasslands are among the largest biomes in the world. Their area is estimated at 52.5 million square kilometres or 40.5 percent of the terrestrial area, excluding Greenland and Antarctica. They are the great genetic reservoir of forage species for sustaining and improving the productivity of pastures used for intensive livestock production in all environments and support pastoralist and ranching systems that form the livelihood of several hundred million people, largely, but not solely in developing countries. They are extremely important environmentally as a major form of vegetation, and play a vital role for animal production, soil erosion control and carbon sequestration; they are a major reserve of biodiversity, a cheap and safe form of *in situ* conservation of genetic resources, and important wildlife habitat.

In most areas the composition of natural grasslands has been modified, often profoundly, by interventions such as periodic burning, grazing by livestock, providing water points to, or oversowing with grass or legume seeds. A small proportion of grasslands globally, but dominant in many countries, has been converted into often high-yielding pastures of purposely sown species mixtures or of a single or a few cultivars. Large areas of natural grasslands in more favoured environments have been converted to crop lands, relegating grazing to more marginal areas, less suited to cropping. This conversion of much of the natural grasslands, has resulted in the loss of genetic resources that are valuable for maintaining highly productive sown pastures in the same and similar environments.

Sown pasture within arable rotations is important, mainly in temperate regions, for livestock production and fertility maintenance in rotations. Cut and carry fodder is locally important, especially for smallholders.

Grasslands and forage species have adapted over the centuries to increased human and animal pressure, to erosion, and climate changes. They have continued to provide food and fibre for the world's growing human and grazing animal populations through their flexibility and adaptation. In dry lands pastoralists have developed management systems adapted to uncertainty of water and forage availability.

The most sustainable way of maintaining thousands of grassland species that hold potential for many future uses and services, is to promote their *in situ* conservation by responsible and educated farmers and pastoralists. Grassland must be grazed and managed if it is to be conserved – it can not be enclosed and left undisturbed. The condition of natural grasslands is a serious issue for *in situ* conservation. They are everywhere degraded, often seriously. This means that, in a large part of the world and for much of the genetic base, *in situ* conservation is problematic. Land pressures are increasing, and unless there is a massive international determination to conserve grassland areas, there may be limited value in *in situ* conservation in large parts of the world in twenty years from now.

There is little or no historical record of grassland condition, but according to UNEP already 69.5 percent of dry lands are degraded. Many countries lack an inventory of grasslands, their condition and biodiversity and systematic information on grassland and forage species. Worldwide, efforts are needed to assess, inventory, monitor and document the national heritage of grassland and forage species genetic resources.

The genetic base of sown pastures is very narrow: for example, more than three-quarters of the grass cultivars registered in the European Union are of just six species, and more than half of *Lolium perenne* and L. *multiflorum* which account for more than 80 percent of the forage grass seed sold in the EU. In the tropics, the genus *Brachiaria* is playing a similar role. In Brazil alone it accounts for some 60 million ha of sown pasture, half of which is *B. brizantha* cv Marandu; a single *B. decumbens* cultivar is being adopted in large areas in some Southeast Asian countries and Australia. The potential for massive and widespread pest or disease attacks on such large expanses of single cultivars in monoculture highlights the urgent need to widen the choice of available high-value grass and legume cultivars by exploring, evaluating and selecting from a wide range of species of several genera.

Most major staple food crops are "mandate" crops of CGIAR centres which are well placed to assess their overall global situation. Forage and grassland species are poorly covered by the CGIAR centres and there is a lack of information on and attention paid to, them.

Domestication of temperate grasses has mainly been in the past 250 years and systematic selection is little over a century old. Selection and breeding of temperate forages are actively pursued in Western Europe, USA and New Zealand, but collection, evaluation and cultivar development of tropical species which were only started on a large scale by CSIRO, EMBRAPA and CIAT in about 1950, are now all but abandoned due to lack of funding. Very little is being done to improve the productivity and widen the genetic base of pastures in tropical, subtropical, mountain and dryland environments. A very small proportion of the germplasm of the main forage genera is secured in long-term storage facilities. In the last decade, the level of activity in collection, storage and evaluation of forage germplasm has been declining because of reduced funding.

After a promising species has been identified, evaluated and developed into a cultivar by selection or breeding, the seed of the resulting cultivar has to be made available to farmers for testing and use. Infrastructure, logistics and financial services for efficient grass and legume seed production, distribution and widespread use are not in place in many developing countries.

Even though many countries hold a significant amount of plant genetic resources for food and agriculture in their natural grasslands, farmers' fields and gene banks, virtually all countries have benefited and will benefit from access to additional diversity, including from the species' centres of origin.. Such a wider range of available germplasm will, for example, enable the introduction of mixed crop-livestock farming systems in a wider range of ecosystems and farming conditions, increasing productivity and resilience against effects of economic shocks, climate change and desertification and broaden the scope for introduction of energy crops that do not compete with food or conventional industrial crops.

There is a great need for mechanisms to exchange genetic resources of grassland and forage species between countries to ensure a world wide improvement of livestock production for sustainable food security to the benefit of millions of people, particularly in developing countries. There are many examples of genetic resource exchanges, some of them dating back to ancient times. The oldest example of global dispersion of a forage crops is alfalfa/lucerne, which originated in Asia Minor and north-western Persia. It was introduced to Greece in about 490 BC, spread to Italy in the first Century AD and to Spain in the eighth Century AD. From there the Spaniards took it to Mexico and South America. From Mexico it was taken into the southern States of the USA and in 1854 it was taken to San Francisco from Chile. *Brachiaria* originated in Africa and is now used in some 100 million hectares of sown pasture in Latin America and Southeast Asia

The wide range of germplasm needed for this can only be identified, collected and evaluated with the consent and cooperation of its traditional guardians: pastoralists and farmers, who have maintained the diversity of their grassland resources, and improved some of the genetic material, through its use and management. They will also need to share in the benefits derived from such germplasm. Such development and use of grassland genetic resources, and even their continued *in situ* conservation, can only be achieved through clearly agreed cooperation between and among many actors: governments, international agencies and international and national research institutes, industries, farmers' and pastoralists' communities, non-governmental organizations, and consumers.

The genetic base of the world's nationally important food and industrial crops is contained in some 120 species, more than a quarter of which, in more than 35 genera, are covered by the Multilateral System (Part IV and Annexe 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture, 2001). The genetic base of the world's sown pastures and natural grasslands comprises a vastly greater number of genera, largely grasses and legumes, of which less than 30, almost all from temperate environments, are covered by the Multilateral System. Virtually none from tropical, subtropical, mountain or dryland environments are covered by the System so far. Such coverage would facilitate their international exchange and dissemination under equitable conditions for local selection and adaptation, increasing grassland and livestock productivity in these environments. This report contains, in Annex 2, a list of important pasture species not mentioned in Annexe 1 of the Treaty.

Hence there is a need to develop specific instruments and activities, guided by the Commission on Genetic Resources for Food and Agriculture and its Intergovernmental Technical Working Group on Plant Genetic Resources. They would constitute components or elements under the existing framework for the responsible exploitation, management and conservation of the genetic resources of forage crops and grasslands: the Global Plan of Action for Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture, which was reinforced by the International Treaty. Such elements could be regulatory instruments, contractual arrangements, bilateral and multilateral funding modalities, voluntary agreements, standards or codes of conduct, and cooperative arrangements and alliances for, for example, the exchange, structuring and dissemination of information, findings and insights.

The paper discusses the characteristics of grasslands and fodder crops, the major issues related to forage genetic resources maintenance, use and importance of their biodiversity, grassland and forage genetic resources, genetic resource conservation, use, productivity and management of grassland and forage genetic resources, environmental concerns, and auxiliary use of forages and grasslands species.

# 1. INTRODUCTION

This document provides insight and information related to grassland species and fodder crops. It discusses the value and roles of forages and grassland species for food security and poverty alleviation, as well as issues related to the management of their genetic resources. The relations between forages and livestock production are stressed; meat and milk are derived from forage plants which are, for the most part, inadequately collected, documented and exploited. Additional information on the relation between the management of grasslands and animal genetic resources can be found in Study H: "Interaction between plant and animal genetic resources, and opportunities for synergy in their management".

Fodder and pasture are commercialised through livestock. Fodder is integrated into mixed croplivestock systems but may be produced as a source of supplementary feed for extensive grazing. Dried fodder, and occasionally green feed, are traded. Where smallholder dairying is profitable, fodder is grown to supplement crop residues which form the basis of feeding. Fodder (and young pasture growth) may be conserved, as hay or silage.

## 1.1 The structure of the paper

After the Introduction, Chapter 2 deals with the characteristics of grassland, pasture, fodder crops, crop residues, biological nitrogen fixation, grazing under tree crops and cover and green manure crops. Both grazed pasture and cut-and carry fodders are involved; the latter being especially important in smallholder systems.

Chapter 3 discusses the main issues of forage plant genetic resources and the role and uses of grasslands for benefits to people and the environment, besides livestock production.

Chapter 4 gives an overview of the different types of grassland; the development and adoption of improved forage cultivars; the role of pastoralists (herders) and smallholders in the maintenance of forage plant genetic resources; interdependence and accessibility of genetic resources and ancient and existing examples of the migration of genetic resources across he world and the need for documentation and monitoring of species diversity, for inventories of existing collections in order to facilitate plan and allocate priorities for collection and conservation activities.

Chapter 5 describes genetic erosion and genetic resources conservation *ex situ* in gene banks and *in situ* in the field, particularly in natural grasslands that are managed and used by traditional livestock owners.

Chapter 6 describes uses and productivity of forage genetic resources in grasslands (meat and milk), organic systems, mixed farming systems, traditional and commercial extensive grazing systems and the use of cut-and-carry fodder by smallholders.

Chapter 7 deals with environmental concerns: global warming, carbon sequestration, methane and nitrogen emissions, problems with plant introductions, diseases, pests, invasive species and weeds.

Chapter 8 is about other uses of forage and grassland genetic resources: conservation agriculture, amenity grassland, production of alkaloids, aromatic substances, fertility maintenance, traditional medicines, bio-energy and erosion control.

Chapter 9 summarises the conclusions of the study.

Terminology in English on grassland, pasture and fodder (and many variations) is very imprecise and usage varies regionally. To avoid misunderstandings the terminology used in this paper is reported in the Glossary of Technical Terms (Annexe 3). a list of acronyms is given in Annexe 4.

# 2. CHARACTERISTICS OF GRASSLAND AND FODDER CROPS

## 2.1 The structure of the paper

**Grassland** is all grassy vegetation (pasture, savanna, extensive grazing lands, open woodland, rangeland); it is the main source of forage, the chief herbaceous feed for domestic and wild herbivores. Grassland is a vegetation type (c.f. forest) defined as ground covered by vegetation dominated by grasses with little or no tree cover. UNESCO (1979) defined grassland as land covered with herbaceous plants with less than 40 percent tree cover. While grasses are the basis of grasslands some Cyperaceae and Juncaceae are important in swards and are grouped with grasses as "graminoids".

**Natural grassland or Rangeland** is grazing land consisting of native or unimproved species, whose management is restricted to grazing, mowing, burning and woody weed control

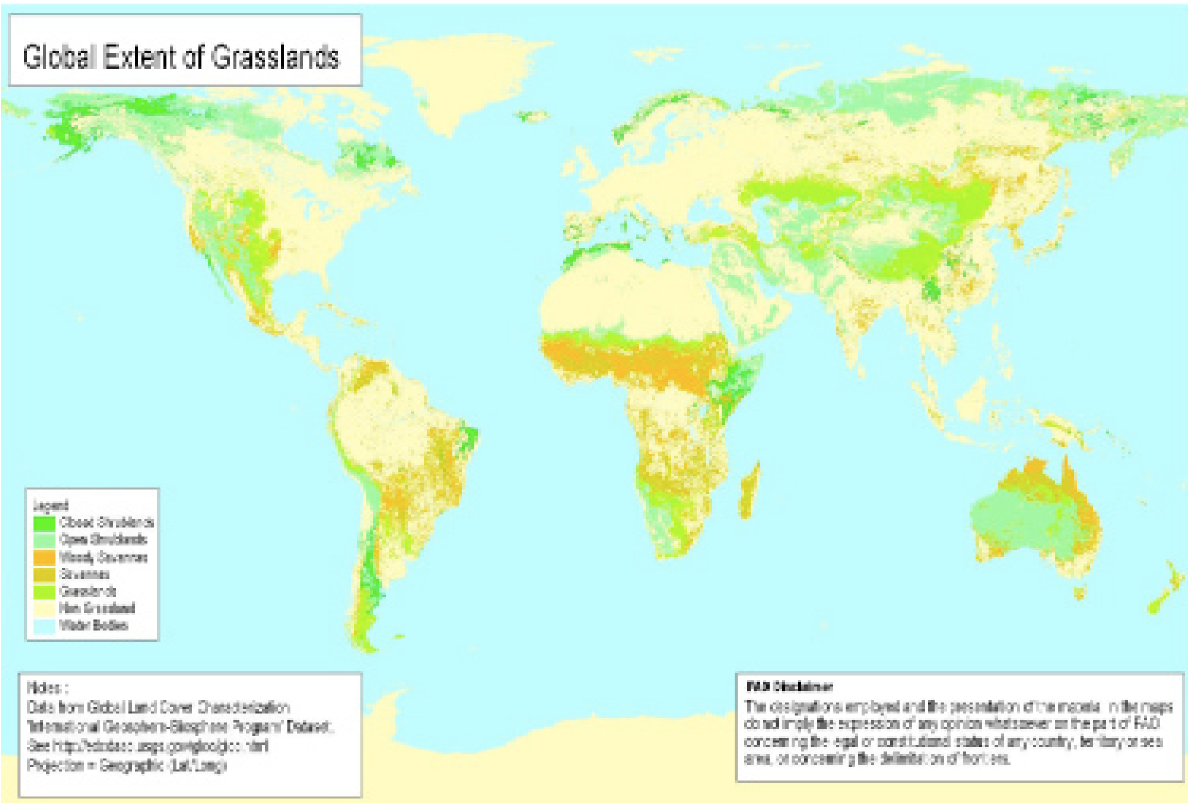
**Savanna** is wooded grassland with up to 40 percent tree cover

**Sown pasture** is forage sown for grazing, usually for a duration of several years. It is important in commercial, arable farming systems and must be economically competitive with other crops, at the farm system level. It often forms part of an arable rotation in mixed farming systems

**Fodder crops** are grown on arable land and harvested as a whole crop for livestock feed. Many are also field crops, cereals and pulses, others are specialised fodders. Fodders are only grown where they are economically competitive with field crops.

## 2.2 The world's grasslands

PLATE 1.
**The world's grasslands**




Source. Grasslands of the World (Suttie et al. 2005)

Natural grasslands are found in dry or cold areas where trees do not persist. In the wet tropics they occur only in frequently flooded land.

No grassland is entirely natural and there are many degrees of interference: fire, spontaneous or lit by man has influenced, and continues to influence large areas; grazing by livestock and on some continents, by large herds of wild herbivores and a series of more invasive agronomic interventions up to oversowing – with or without surface scarification and fertiliser. Grassland is said to be natural if it is not the result of full ploughing and sowing – the composition of much old sown pasture has, of course, little to do with the seeds mixture used at its establishment (Suttie *et al*. 2005). The mosaic of uncultivated patches within farming land, is important in smallholder systems; in commercial systems it is more important as a wildlife habitat and a refuge for biodiversity. To be of use for livestock grassland must be accessible. Lack of watering points is one reason for inaccessibility; infestation by tsetse fly is a common cause of inaccessibility in the moister lowlands of Africa.

Grasslands are among the largest biomes in the world. Their area is estimated at 52.5 million square kilometres or 40.5 percent of the terrestrial area, excluding Greenland and Antarctica (World Resources Institute 2000, based on IGBP data). Fourteen percent of the global land area (excluding Greenland and Antarctica) is open woodland and savanna, 13 percent is open and closed shrub, 8 percent is tree-less grassland and 6 percent is tundra.

Great grazing lands still exist: among the most important are the steppes stretching from Mongolia and Northern China to Europe, the Tibet-Qinghai Plateau and the adjacent mountain grazing of the Himalaya-HinduKush, the high altitude, alpine ecosystems, the North American prairies; in South America - the Pampas, the Chaco, Campos, Llanos and Cerrados pastures, the cold lands of Patagonia, the Altiplanos; and the Australian Downs. In the Mediterranean Region and Western Asia there are large areas of semi-arid grazing land. South of the Sahara are the vast Sahelian and Sudano-Sahelian grasslands and most of eastern Africa from the Horn to the Cape. The condition of most extensive grasslands is poor and deteriorating; unless action is taken to reverse the degradation their value for *in situ* conservation of genetic material will be severely limited. A recent FAO study, Grasslands of the World (Suttie *et al*. 2005) is available at http://www.ao.org/documents/show_cdr.asp?url_file=/docrep/008/y8344e/y8344e00.htm.

In Western Europe, grasslands occupy 30-40 percent of the agricultural area; in Central and Eastern European countries that previously had centrally planned economies (the Russian Federation not included), grassland occupied about 30 percent of the agricultural area (Peeters, 2004). This percentage is expected to increase, as the population's purchasing power for animal products increases. Sown pasture is important in these regions.

Grasslands limit water and wind erosion. In North America and Central Asia, ploughing the steppes brought about catastrophic wind erosion in many places (Texas, Oklahoma, Colorado, the Dakotas, Kazakhstan, and Uzbekistan). All grassland areas favour the development of organisms that decompose organic matter. Earthworm populations, for example, are much greater under grassland than in arable land. An earthworm biomass of 1 000–5 000 kg $ha^{-1}$ can be found in grassland compared to less than 500 kg ha-1 under annual crop (Granval *et. al.* 2000).

## 2.3 Grasses

Grasses belong to the family *Poaceae* (*Gramineae*). About 750 genera and 12 000 species, occur in all climatic zones. There are 7 subfamilies: *Arundinoideae*, *Bambusoideae*, *Centhothecoideae*, *Chlorideae*, *Panicoideae*, *Pooideae* (*Festucoideae*) and *Stipoideae*. A few genera are woody, notably the bamboos, most are herbaceous. The *Paniceae* mostly occurs in the Western and the *Andropogoneae* in the Eastern hemisphere. The Poaceae is the fourth largest family of flowering plants after the *Orchidaceae*, the *Compositae* and the *Leguminosae*.

Many grass species contribute to grassland but only about 70 species represent 99 percent of the grasses used in sown pastures and which are subject to genetic improvement. These belong largely to the *Pooideae* (temperate regions) and the *Panicoideae* (tropical and sub-tropical regions). The most important centres of genetic diversity for sown grasses are East Africa, Eurasia, and to a lesser extent South America.

Many grasses contain ecotypes with a range of ecological adaptation and cultivars have been developed within species to suit very varied conditions. *Lolium perenne* occurs in nature in cooler Eurasia as far south as the desert fringe. In humid temperate climates L. *perenne* is summer-growing and winter dormant: Mediterranean ecotypes are dormant during the hot summer. *Dactylis glomerata* similarly has summer growing and winter growing ecotypes.

Many species of the subfamilies Chloridoideae (syn. *Eragrostoideae*) and Panicoideae have a different $CO_2$ assimilation pathway ($C_4$) from most grasses and other angiosperms ($C_3$). The *Chloridoideae* prefer hot, dry habitats and increase in dominance with increased grazing pressure and N availability. The *Panicoideae* usually prefer humid, wet environments and decline in importance with increasing grazing pressure and increased soil N. The Pooideae (Festucoideae) comprise mostly $C_3$ species from the cooler climates.

$C_4$ grasses in comparison with $C_3$ grasses:

- require higher temperatures for growth and have thicker cell walls, less mesophyll, more sclerenchyma and more bundle sheaths, and consequently a lower digestibility and so lower voluntary intake by herbivores
- use water more efficiently and thus show greater drought tolerance
- produce more dry matter (DM) per unit of time and area
- have greater N efficiency and as a result lower crude protein (CP) concentration and lower feeding value
- have lower water-soluble carbohydrate reserves and require special treatment (sugar addition) for making silage ('t Mannetje, 2000a).

The main cultivated grasses of temperate regions are: *Bromus catharticus*, *Bromus inermis*, *Dactylis glomerata*, *Elymus* spp., *Festuca arundinacea*, *Festuca pratensis*, *Lolium multiflorum*, *Lolium perenne*, *Phalaris aquatica*, *Phalaris arundinacea*, *Phleum pratense*, and *Poa pratensis*. In mixed farming systems except in the coldest areas *Lolium* spp. are very important as are *Dactylis glomerata* and *Phleum pratense*.

The main tropical grasses were collected and brought into cultivation in Africa during colonial times (Bogdan 1977; Boonman 1993), but their development on a large scale only started after 1950. Important tropical grasses that have gone through a selection activity or cultivar development include *Andropogon gayanus*, *Axonopus compressus*, *Bothriochloa* spp., *Brachiaria brizantha*, *Brachiaria decumbens*, *Brachiaria mutica*, *Brachiaria ruziziensis*, *Cenchrus ciliaris*, *Chloris gayana*, *Cynodon aethiopicus*, *Cynodon dactylon*, *Cynodon nlemfuensis*, *Dichanthium annulatum*, *Digitaria decumbens* (=D. *eriantha*), *Eragrostis curvula*, *Melinis minutiflora*, *Panicum antidotale*, *Panicum coloratum*, *Panicum maximum*, *Paspalum dilitatum*, *Paspalum notatum*, *Paspalum plicatulum*, *Pennisetum purpureum*, *Setaria sphacelata*, and *Tripsacum laxum*.

At least 60 percent of tropical forage grass species reproduce by apomixis [asexual reproduction by means of seeds] (Hacker and Jank, 1998): these include *Brachiaria brizantha*, *Brachiaria decumbens*, *Brachiaria humidicola*, several species of *Paspalum*, *Panicum maximum*, *Cenchrus ciliaris*, *Melinis minutiflora*, and *Hyparrhenia rufa*. Species like *Andropogon gayanus*, *Brachiaria ruziziensis*, *Pennisetum purpureum*, *Paspalum notatum*, *Setaria sphacelata*, *Chloris gayana*, *Cynodon dactylon* and *Cynodon nlemfuensis* reproduce by cross-pollination. Within a genus, apomixis and crosspollination may be found in different species (Valle and Glienke, 1991; Burson, 1997).

Breeding of apomictic species depends on the availability of totally, or highly sexual plants which are found in the species' centre of origin. Apomixis in *Panicum maximum* and *Brachiaria* is the result of apospory followed by parthenogenesis (Savidan, 1982; Valle and Savidan, 1996). In apospory, meiosis occurs, but all four megaspores abort, and a somatic cell of the nucellus develops into an egg, which is, therefore, 2n and of the maternal type. Subsequently, fertilization of the egg cell fails and through parthenogenesis the 2n egg cell develops and forms the embryo. The sperm does, however, fertilize the polar nuclei, which become 3n. The ratio embryo/endosperm 2n/3n confers the fertility to the seeds (Savidan, 1982).

Eastern and south-eastern Africa is an important region of diversification for tropical grasses. Although pasture grasses were developed and used in East and south-eastern Africa, their great development has been in Australia and tropical Latin America.

## 2.4 Legumes

Legumes are important for the high quality of their forage and their ability to fix atmospheric N, through symbiotic bacteria in their root nodules. The approximately 18 000 species of legumes belong to about 670 to 750 genera which include important grain, pasture, forest and agroforestry species.

Legumes are divided into three subfamilies: *Caesalpinioideae*, *Mimosoideae*, and *Papilionoideae*. Within the *Caesalpinioideae* and the *Mimosoideae* 96 percent are tropical trees and shrubs, of which *Leucaena leucocephala* is widely planted and the herbaceous *Chamaecrista rotundifolia* is sown to some extent; other genera, particularly *Acacia*, are important as browse in rangeland. Most herbaceous legumes belong to the Papilionoideae.

The main centre of genetic diversity of temperate legumes is the Mediterranean (e.g., *Hedysarum coronarium*, *Lotus* spp., *Medicago* spp., *Onobrychis viciifolia*, *Trifolium* spp.). *Trifolium hybridum* is native to Eurasia. For tropical species the main centres of genetic diversity are South and Central America (e.g. *Arachis*, *Stylosanthes*, *Desmodium*, *Centrosema*, *Leucaena* and *Gliricidia*), whilst Africa and Asia are important for the genus *Neonotonia*, Asia for *Pueraria* and some species of *Desmodium*; Africa for *Lotononis*. Most pasture legumes, like grasses, are of recent domestication, except alfalfa/lucerne, *Medicago sativa*, (which was domesticated before the Christian era in what is now northern Iran). and Egyptian clover (*Trifolium alexandrinum*)

## 2.5 Other botanical families in grasslands that are important genetic forage resources

Grazing lands mainly contain grasses, but other families also play an important role in livestock production and ecosystem services. Cyperaceae are especially important in cold, damp sites, *Carex* and *Cyperus* are locally common and *Kobresia* covers large areas of closely grazed mountain meadow in Himalaya and China (Ruijun 2003). Sub-shrubs dominate large areas of grazing land: Artemisia spp. associated with other shrubs is very widespread in steppe lands and some of the drier parts of North America. In dry, saline sites Chenopodiaceae including *Atriplex* and *Kochia* spp. are important.

Large areas of moorland in Western Europe are dominated by Ericaceae – *Calluna*, *Erica* and *Vaccinium*.

## 2.6 Sown pasture

Sowing pasture developed in Western Europe once farms were enclosed and the tumble-down fallow of the village system could be developed, within rotations, for forage production. (see section 6.2) It is associated with large to medium farms. Fields have to be large enough to allow management of herds of grazing animals and generally require fencing and sometimes water supply.

Domestication of temperate grasses has mainly been in the past 250 years and systematic selection is little over a century old. Choice of pasture species and cultivar depends on the prevailing agroecological conditions as well as the use to which the pasture will be put; pasture as a crop has a high degree of species substitution.

A large pool of genetic variability, among and within species, is available; this diversity, still not fully tapped, coupled with a greater understanding of the physiological basis of variation in yield and persistence, is leading to continued substantial improvements in cultivars. The number of species in some genera is great; *Trifolium*, has about 250, yet only a dozen or so are currently important in agriculture.

A key feature of forage species is their intrageneric adaptation to different environmental and management conditions. Species of many grasses and the genera *Trifolium* and *Medicago* have a wide latitudinal range from northern and southern cool temperate regions to high altitude areas with dry, cold winters in subtropical and tropical regions.

Selection and breeding of food crops and alfalfa date to early agricultural history. Selection and breeding of temperate forages are actively pursued in Western Europe, USA and New Zealand, but collection, evaluation and cultivar development of tropical species only started on a large scale by CSIRO, EMBRAPA and CIAT in about 1950, and is now all but abandoned due to lack of funding.

Molecular markers are becoming increasingly important in forage crop germplasm research. They are useful in managing germplasm collections, by helping to identify novel or redundant accessions, quantifying genetic variability within and among accessions, measuring contamination during seed multiplication, or determining the geographic distribution of genes or gene sequences. Molecular data on germplasm collections can also be used to make decisions regarding the most useful germplasm for incorporation into breeding programmes (Quesenberry and Casler 2001).

### 2.6.1 Biological nitrogen fixation

Atmospheric nitrogen (N) is fixed in symbiosis with pasture legumes, including shrubs, by bacteria of the genera *Rhizobium* and *Bradyrhizobium*, which infect the legume root-hairs inducing nodules. Rhizobial species are specific to individual legumes or groups of legumes (Sprent and 't Mannetje 1996; Frame 2005). Rhizobia are an essential part of the genetic resources of forage legumes. Fixed N is transferred to companion grasses indirectly through root and litter decay as well as being returned to the sward in the excreta of grazing animals (Laidlaw and Teuber 2001).

Biological nitrogen fixation accounts for about 65 percent of the N used in world agriculture (Graham and Vance 2000), a high proportion of which is fixed by forage legumes. Hauck (1984) estimated that about 50 million tonnes of N are fixed annually by forage legumes. The efficiency of the plant- *Rhizobium* symbiosis is a key factor in legume technology and N supply for soil fertility. Subsequent arable crops benefit from the residual N left in the soil.

The amount of N a legume fixes is a function of its dry matter production, irrespective of species. Estimates of N fixation by tropical pasture legumes are between 30 and 170 kg $ha^{-1}$ $yr^{-1}$ for average and 290 kg $ha^{-1}$ for good legume growth in tropical and subtropical Australia (Henzell 1968), 30-80 kg N $ha^{-1}$ $yr^{-1}$ for *Stylosanthes hamata* in the dry tropics of Queensland (Vallis and Gardener 1985) and 67-117 kg N ha-1 yr-1 for *Stylosanthes* spp. in the Cerrados of Brazil (Cadisch *et al*. 1993).

Frame (2005) presented median values of N fixed by temperate forage legumes for the commoner species (kg N $ha^{-1}$ $yr^{-1}$) as: alfalfa/lucerne 180, red clover 170, birdsfoot trefoil 92 and forage peas 72. Values of 99 – 231 kg N $ha^{-1}$ $yr^{-1}$ were found for white clover in association with perennial ryegrass in New Zealand (Ledgard *et al*. 1999).

### 2.6.2 Grass-legume mixtures

There is a return to the use of legumes in temperate pastures as part of the movement to more environmentally friendly farming, to reduce nitrate leaching and reduce costs. Legume mixtures figure largely in organic farming systems. Mixtures may be of a grass and a legume or of a range of grasses and legumes. The advantages of mixtures are: grasses provide bulk and form a sward; legumes, infected with an effective rhizobium, increase the supply of N to the grasses and protein to livestock; the combined herbage is of higher nutritive value than grass alone; mixtures may provide a longer season of production of palatable herbage than pure stands of one cultivar of grass or legume; the grass absorbs N made available by the legume – pure pastures of legume would become weed infested; long-term use of self-reseeding legumes in the Mediterranean areas of Australia led to soil acidification through excess nitrate production which is leached down the soil profile (Kemp and Michalk 2005). In tropical Australia the use of stylosanthes is giving similar problems (Noble *et al*. 1997).

Mixtures must be so managed that their components remain in balance and an adequate amount of legume is maintained to provide enough N to ensure a vigorous sward. Legumes with rooted nodes and low growing points are best suited to grazing mixtures.

For temperate conditions *Trifolium repens*, which stands continuous grazing well, is by far the most widespread and well adapted. *Medicago sativa* and *Trifolium pratense* are better suited to rotational grazing or mowing. For tropical pastures in humid and sub humid climates *Arachis pintoi* is highly grazing tolerant and may dominate the sward at high grazing pressures. Many tropical pasture legumes have a trailing or scandent habit which makes them sensitive to grazing.

## 2.7 Fodder crops

Fodder crops are grown in arable production systems. They suit both large and small-scale holdings since they are usually cut and transported to the livestock and field size is unimportant. Some dried forage, and occasionally green feed, is traded. Fodder crops, often irrigated in semiarid areas, can provide conserved forage for winter use or to supplement crop residues, which are a staple feed of cattle in many smallholder systems. Fodders may be fitted into gaps in cropping patterns which would be too short to allow a field crop to ripen (catch crops).

Fodder crops can be roughly divided into specialised fodders, mainly cereals and pulses and field crops grown for forage.

Fodder cereals include oats (*Avena sativa* and *A. strigosa*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum americanum*), barley (*Hordeum sativum*), rye (*Secale cereale*), proso millet (*Panicum miliaceum*) and finger millet (*Eleusine coracana*). *Saccharum officinarum* is also used as forage. There has been a great expansion in the use of fodder oats recently, in areas of mild winters; they are the subject of a recent FAO study (Suttie and Reynolds 2004). Federizzi and Mundstock (2004) reported that two million ha of fodder oats were grown in Argentina and Uruguay and over three million ha in Brazil in 2003.

Most of the temperate pasture grasses can also be used for mowing. Several large, perennial, tropical grasses are grown for forage including: Elephant grass (*Pennisetum purpureum*), the larger cultivars of Guinea grass (*Panicum maximum*) and Guatemala grass (*Tripsacum laxum*). They are of particular interest to smallholders. Annual tropical or hot-season grasses which are specialised forages include: Teosinte (*Zea mexicana*), Sudan grass (*Sorghum x drummondii*), Columbus grass (*Sorghum almum*) and Johnson grass (*Sorghum halepense*).

Pulses used as forage include pea (*Pisum sativum*), guar (*Cyamopsis tetragonaloba*), pigeon pea (*Cajanus cajan*), soybean (*Glycine max*), hyacinth bean (*Lablab purpureus*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), and fenugreek (*Trigonella foenum-graecum*).

Perennial legumes used as fodder crops include: alfalfa/lucerne (*Medicago sativa*), sainfoin (*Onobrychis viciifolia*), red clover (*Trifolium pratense*), and Alsike clover (*Trifolium hybridum*). Annuals and short-lived perennials include Egyptian clover (*Trifolium alexandrinum*), crimson clover (*Trifolium incarnatum*), Persian clover (*Trifolium resupinatum*), sulla (*Hedysarum coronarium*), vetches (*Vicia* spp.), Chinese milk-vetch (*Astragalus sinicus*), seradella (*Ornithopus* spp.), sweet clover (*Melilotus alba*) and yellow sweet clover (*Melilotus officinalis*).

Root crops were very important in humid temperate agriculture, but have been largely replaced by maize and grass silage. They are mainly members of the Brassicacae – turnips (*Brassica rapa* var. *rapifera*), swedes (*Brassica napus* var. *napobrassica*), kale (*Brassica oleracea*), cabbage (*Brassica chinensis, B. oleracea*), forage radish (*Raphanus sativus*) and fodder beet (*Beta vulgaris*).

Most forage is consumed on-farm. It is also marketed. In commercial systems feed-lots, dairies and stables purchase forage, often as hay. There is also an export market, with increasing demand for livestock feed in Eastern Asia and in some Near Eastern countries. Australia, Canada and the USA are the main exporters. Densified or double compressed long hay is now the product of choice. In 1999 nearly 300 000 tonnes of oaten hay were exported from South Australia and Victoria (Stubbs 2000).

Alfalfa hay and meal is commercialised for concentrate feed for livestock, including pigs and poultry; the USA is a large producer.

### 2.7.1 Cut-and-carry fodders

Mechanised harvesting and feeding of fresh forage is practiced in some commercial systems. Here smallholder systems are discussed.

Fodder crops are of increasing importance in smallholder systems since population pressure has led to disappearance of grazing land in mixed farming areas. Cultivated fodder is increasingly used by smallholders in China, Southeast Asia, South Asia and parts of Africa. Where livestock is economically interesting, notably for dairying, fodder is grown to supplement crop residues. It is cut and carried to stall-fed stock. Livestock are important for income, food security and as a store of capital in many smallholder systems. Fodder trees and shrubs are also involved.

In Sub-Saharan Africa growing crops to feed livestock was an alien concept, but is now developing.

Orodho (2005) described how dairying, based mainly on Pennisetum purpureum (Napier grass) and crop residues, is expanding rapidly in parts of upland Kenya.

Smallholder marketing of forage is important in Pakistan and India where large dairy herds are kept in or around cities and forage and crop residues are the basis of their diet. Forage producers may or may not be stock owners; purchase and marketing is often in the hands of contractors. Dost (2004) describes the situation in Pakistan, where the number of dairy stock in the main towns was estimated at 946 000; the main winter forages are Trifolium alexandrinum and oats. The summer forages are coarse cereals.

Some minor fodders, almost entirely farmer-maintained, have special niches. In Pakistan, Melilotus indica, although replaced by Trifolium alexandrinum on good land, is grown on sites too dry or too saline for the clover; Echinochloa frumentacea is grown on sites waterlogged during the monsoon. In Afghanistan Trifolium resupinatum is an important hay crop (and vegetable) in areas with cold winters, especially on sites with only spring irrigation. Small-scale farmers in northwest Argentina grow alfalfa hay for sale (Suttie, 2000).

China grows large areas of forage, nearly all used in cut-and-carry systems. (Table 1)

TABLE 1
**Major forage crops of China (thousand ha, 1998)**

| Forage | Area |
|---|---|
| *Medicago sativa* | 1 804.7 |
| *Astragalus sinicus* | 1 686.9 |
| *Zea mays* | 570.5 |
| *Hordeum vulgare* | 358.7 |
| *Lolium multiflorum* | 183.2 |
| *Avena sativa* | 155.7 |
| *Vicia villosa* | 123.9 |
| *Avena nuda* | 118.7 |
| *Vicia sativa* | 98.9 |
| *Setaria italica* (forage) | 80.0 |
| *Sorghum sudanense* | 77.2 |
| *Melilotus albus, Melilotus officinalis* | 20.7 |
| *Secale cereale* | 20.1 |
| **Total** | **5 299.2** |

Derived from Hu and Zhang (2003)

In Gansu and Shandong, farmers grow Medicago sativa for hay for sale to processing companies for pellet making. Farmers' income can be increased by more than 15 percent compared to cereal growing (Hu and Zhang 2003).

### 2.7.2 Fodders and monogastric livestock

Fodder is used in the feeding of monogastric livestock and fish. High-protein legume meals, notably lucerne, are widely used in concentrate rations. Monogastric livestock and aquaculture are important in the warmer and better watered parts of China and fodder production for pigs, poultry and fish is increasing. In northern warm temperate agricultural areas, farmers are encouraged to use some, or even all, arable land to grow forages such as lucerne, or to grow *Vicia sativa* after wheat harvest for high quality hay and then raise pigs and poultry. In southern subtropical paddy areas, farmers use the winter fallow to grow *Lolium multiflorum* for pigs, dairy cows and rabbits; a rotation of rice and ryegrass. Annual ryegrass is sown in November and cut every 10 days from December to March (8 to 10 times); its crude protein content is 20 to 26 percent. This system has been extended to more than 2 000 000 ha. (Hu and Zhang 2003). Stylosanthes is now being developed for fish feed in China.

Several specialised aquatic fodders are grown for monogastrics in China (Hu and Zhang 2003) including: *Alternanthera philoxeroides; Aneilema keisak; Azolla imbricata, Pistia stratiotes, Zizania caduciflora, Amaranthus paniculatus*, and *Lactuca indica*, an indigenous biennial herb, grown country-wide for pigs and poultry.

## 2.8 Forage conservation

Forage is usually most readily available at the height of the growing season and loses quality rapidly if not consumed or conserved at the appropriate stage of growth. Storage of forage for later use is a preoccupation of stock-rearers in many areas. The emphasis on conservation depends on the climate. In areas with a marked winter it is usually a necessity, except in transhumant systems. In areas with a continuous thermal growing season, as in much of the tropics, stock rearers try to maintain green-feed. Year-round grazing is rarely feasible in temperate conditions – with notable exceptions in parts of New Zealand.

Hay is the oldest, and still the most important, conserved fodder despite its dependence on suitable weather at harvest time. It can be made with simple equipment, manually but most is highly mechanised. Prospects for haymaking are reviewed by McCartney (2005) and haymaking for smallholders is discussed by Suttie (2000).

Ensiling, a fermentation process, is now a major conservation method on large exploitations in subhumid and humid climates, but is laborious without heavy machinery and not readily adaptable to smallholder conditions: silage is unsuitable for transport over any but the shortest distance since it has a high moisture content and must be protected from the air; it is not marketable.

Ensiling is the best method of conservation of moist crop by-products. Commonly ensiled crop residues are: rejected bananas, banana leaves and pseudostems, roots and leaves of cassava and other starch crops (sweet potato, taro, yams), citrus and pineapple pulps and leaves, tomato pulp, oil-crop residues (oil palm fronds) and by-products (olives, oil palm), seeds and pulp of grapes, brewers' extracted malt and spent grain, fish by-products and poultry litter ('t Mannetje, 2000a). Among temperate crops pea-haulms and sugar beet tops and pulp are ensiled.

## 2.9 Crop residues as livestock feed

Field crops, especially cereals, produce large quantities of stem and leaf in addition to their saleable product, which is usually seed. Straw or stover is usually over half the harvestable vegetation of the crop and cannot be eaten by humans, but can be transformed into economic products by livestock. These residues are coarse roughages, but they are often no worse, and possibly better than, mature, tropical grass. Environmental legislation and the development of straw treatment to improve digestibility, has brought an end to straw burning in most developed countries where it can be either fed to livestock, used for bedding, incorporated in manure, used industrially, used for conservation agriculture, or for bio-energy production.

## 2.10 Fodder trees and shrubs

Leguminous forage trees and shrubs supply high quality, protein-rich forage for subsistence and commercial livestock and yield forage during dry and cold periods when herbaceous species are dormant. They are a source of N-rich mulch in farming systems, provide support for climbing crops, supply rods and round-wood and give shade. Their cultivation as browse is very recent although many have been used for non-forage purposes, such as shade in plantation agriculture, for millennia. *Leucaena*-grass systems have been adopted in commercial farming in Australia because they are sustainable and highly productive. In Southeast Asia small farmers grow leguminous trees as hedges and on field boundaries for multiple benefits: firewood, control of livestock, forage and soil conservation. Trees and shrubs are grown in silvopastoral systems in Central America (Shelton 2005).

There was a lack of genetic diversity in the original introductions, which began a century ago and were often from a few readily-accessible trees. The original *Leucaena* introductions (L. *leucocephala* subsp. *leucocephala*) were weedy, free-seeding and fast spreading throughout suitable climatic zones. Most Prosopis juliflora around the world is of unknown origin and of narrow genetic base. *Gliricidia sepium* in Sri Lanka is reputedly based on a single tree. Improved planting material is now available, but farmers often use the cheapest local seed. N fixation by trees (legumes and others) is discussed by Dommergues *et al*. (1999). The most commonly grown forage tree legumes are shown in Table 2.

TABLE 2
**Most used tree legumes**

| Higher quality species | Lower quality species |
|---|---|
| *Albizia lebbek* | *Acacia aneura* |
| *Chamaecytisus palmensis* | *Acacia nilotica* |
| *Cratylia argentea* | *Acacia tortilis* |
| *Desmodium rensonii* | *Albizia chinensis* |
| *Desmanthus virgatus* | *Albizia saman* |
| *Gliricidia sepium* | *Calliandra calothyrsus* |
| *Leucaena leucocephala* | *Erythrina spp.* |
| *Leucaena diversifolia* | *Faidherbia albida* |
| *Sesbania grandiflora* | *Flemingia macrophylla* |
| *Sesbania sesban* | *Prosopis juliflora* |

Source. Derived from Shelton (2005)

Non-leguminous trees and shrubs are important components of many wooded grasslands. Sub-shrubs are important in steppe, moorlands and garrigue etc.. Wild trees provide browse and shade to wild and domesticated animals as well as fruit and other useful products to pastoral communities. Trees are often lopped for forage by smallholders. Acacias are especially important in Australia and in Africa since, in addition to browse and edible pods, they yield economic products, notably gums and tanning materials. Their role in dry Africa and the Near East is discussed in detail by Wickens *et al*. (1995). Smallholders in Kenya use native trees for browse (Roothaert *et al*. 1997). Panday and Upreti (2005) discuss forage trees in Nepal where the Moraceae is the most widely used family. In some temperate and cold areas browse is also important, notably willow in wet-lands.

A forage tree with a long history of domestication and selection is silkworm mulberry (*Morus alba* and *M. serrata*), which has been cultivated in China for a very long time (Wang Zichun, 1987). Mulberry is widely used in smallholder farming, notably in the Western Himalaya, Afghanistan and Central America (Sanchez, 2002). It is grown for fruit and provides excellent timber (especially *M. serrata*). Mulberry is an excellent and handsome shade tree. Its deep-rooting habit makes it suitable for linear plantings in farmland.

## 2.11 Grazing under tree crops

There are large areas of potential grazing under tree crops in the tropics (Reynolds, 1995). In Southeast Asia plantations are important forage resources. For over one hundred years cover crops such as *Calopogonium mucunoides, Centrosema pubescens* and *Stylosanthes guianensis* have been sown in young plantations for weed control and soil improvement. Light levels in plantations vary from almost full daylight at planting to below 10 percent when the canopy closes at which stage introduced forages are replaced by native vegetation. With coconuts light transmission increases when palms mature. Introduced forages grow well when plantations are young but poor persistence limits their usefulness. There are a few shade-tolerant forages. Grasses like *Axonopus compressus* and *Paspalum conjugatum* perform well as do the legumes *Arachis pintoi*, *Desmodium ovalifolium*, *Calopogonium caeruleum* and *Calopogonium mucunoides*. Grazing for weed control gives low returns so emphasis is likely to be on high-yielding trees with livestock to increase output per unit area (Wong *et al*. 2005). Estates using cattle in Malaysia rose from 120 in 1998 with 56 000 cattle to 167 with 115 400 in 2000. Positive results in Malaysian plantations have led to a national policy whereby the sector is expected to contribute 240 000 tons of red meat by 2010 (Wong *et al*. 2005).

## 2.12 Cover crops and green manures

Leguminous cover crops and green manures date back more than two thousand years in the Mediterranean basin. In the past 50 years, due to the availability of cheap fertilizers, they have been neglected. Many tropical forage legumes were first cultivated as cover crops for rubber, coconut and oil-palm plantations. Green manures are usually fast-growing annuals grown to improve soil fertility and to protect crop land between main crops. They may be catch crops and are usually ploughed under. Green-manuring is staging a come-back in organic farming systems.

# 3.MAJOR ISSUES RELATED TO FORAGE GENETIC RESOURCES MAINTENANCE, USE AND IMPORTANCE OF THEIR BIODIVERSITY

Grasslands are extremely important environmentally as a major form of vegetation, and play a vital role for animal production, soil erosion control and carbon sequestration; they are a major reserve of biodiversity, a cheap and safe form of *in situ* conservation of genetic resources, and important wildlife habitat. Some grasses are serious weeds.

Most major staple food crops are "mandate" crops of CGIAR centres which are well placed to assess their overall global situation. Forage and grassland species are poorly covered by the CGIAR centres and there is a lack of information on and attention paid to them. Through sub-regional FAO meetings, Governments cited the need for more research, market development, inventories and exchange of information; a number of meetings called attention to the importance of grassland species, and species useful in dry and agriculturally-marginal environments.

**There is a need to extend the number of species and cultivars under selection, use, and maintenance and acknowledge the work of pastoralists and farmers who manage and maintain these genetic resources.** On a world scale, only about 100 to 150 forage species have undergone selection, or have been cultivated, from a total of 12 000 species of grass and 18 000 species of legumes. Insufficient attention has been given to the work of farmers and pastoralists who have managed and maintained forage species, in natural grassland, which are suited to particular ecological conditions, often resistant to stress, water shortage and pest attacks, and that hold potential for new farming systems.

**There is a need to increase stock-taking and information about grassland and forage crops genetic resources for food security and also to enhance their safe in situ and ex situ conservation.** Genetic resources of forage and grassland species for food and agriculture consist of the diversity of genetic material contained in traditional landraces and modern cultivars grown by farmers as well as wild relatives of crops and wild plants that can be used as food for humans and feed for wild and domestic animals that produce meat, milk, draught power, dung and fibre. They have, or are seen as having, economic or utilitarian value. Forages are increasingly finding new uses in monogastric livestock and fish, especially in Asia. Following the guidance of the Commission, emphasis in this Report is given to the PGRFA of forage and grassland species that contribute to food security.

**There is a need to recognize the different functions of grassland and forage crop genetic resources.** In the context of new and changing human needs and with an increased awareness of the global risks related to water shortage, pollution, desertification, climate change, food security and health; grasslands are increasingly valued for different purposes and functions, besides their function in animal nutrition, in cropping systems, and with legumes as a source of nitrogen in farming systems. Since grassland plants comprise a very large number of species and of ecotypes within species, grassland has a high degree of adaptability to climate change through species substitution; this is broadly true for fodder crops.

Some important non-grazing uses of forage genetic resources are: amenity planting and sports fields, soil conservation, fertility maintenance, landscape enhancement, and restoration of degraded sites. Bio-energy and fibre production from grassland and forage species hold a great economic potential for the development of new economic systems in the coming decades. Pasture and fodder can be grown on more marginal land than field crops and may increasingly replace concentrate feeds since a lot of the area of grain for feed may be going into biofuel production.

Auxiliary uses of grassland plants are discussed in Chapter 8. The vast pool of genetic variability offers further scope for maintaining and developing cultivars adapted to a wider range of edaphic, climatic and biotic conditions, including marginal and degraded lands, dryland and winter-cold zones.

Extensively managed grasslands are major sites for wildlife and for *in situ* conservation of plant and animal resources; they contain a wide range of pastoral plants, most not yet cultivated, as well as the relatives of cultivated pasture plants; they contain many plants of economic importance including those of interest to traditional and conventional medicine, beginning to be cultivated. They contain pioneer plants for degraded environments and many grasses that hold potential for food production (as well known by traditional farmers and pastoralists who collect wild cereals from grassland). Grasslands are important for recreation, sport and tourism. Because of their vast extent they are important catchment areas and proper management of pastoral vegetation is necessary to ensure maximum retention of precipitation.

The overall management of extensive grazing lands must be done within a wide framework, on a landscape scale, so that it is effective in dealing with the whole range of pastoral resources and products, covers the migration territories of transhumant groups (especially important in the drylands of Asia and Africa) as well as conserving wildlife and catchments. In traditional areas pastoralists often live in small, poorly organized groups. Better planning and management is only likely to succeed if pastoral populations are assisted to organise themselves into larger groups, which can enter into dialogue with one another and the authorities, not only to participate but to play a leading role in planning and management processes at an economic and landscape scale. The general public benefits from the proper management of catchments, landscapes for wildlife, tourism, conservation of biodiversity, recreation and hunting, but the management costs fall on the graziers, be they traditional or commercial.

In many areas commercial stock-rearing on extensive grassland is in economic difficulties and the peoples of traditional systems are mostly poor to very poor. How can those who manage the grasslands be encouraged to do so for the general benefit and how can they be recompensed for adjusting management to even more environmentally friendly ways (Reynolds *et al*. 2005)

## 3.1 Competition between forage production and other land uses

Fodder crops, grown on arable land, have to compete economically with other crops but may be fitted into temporal and spatial niches unsuited to field crops. Sown pastures are also an economic choice within a farming system. Farmers will only grow them if they increase the profitability of their system; rotational advantages and fertility maintenance may be involved.

Extensive grasslands are on land which is unsuitable for crops because the climate is too dry or too cold, the soil too shallow or infertile, the topography too steep, or if there are no ready markets for crops they can be exploited as grazing land.

### 3.1.1 Competition in semi-arid and arid drylands

Grassland, even on poor soils, is often a land-use choice since the same land might be suitable for afforestation, wildlife, tourism or sport. In arid and semi-arid areas with open access or traditional grazing rights the choice may not exist since pastoralists rely on livestock for their livelihood and often for part at least of their subsistence.

## 3.2 Conversion of grassland to crops

Much of the world's mesic grasslands have been converted to crops, notably in the North American Prairie, the South American Pampas, and the East European Steppe. Grazing is now relegated to the more marginal lands, unfit for cropping, where the population is often totally dependent on livestock for its livelihood. In Africa there is little extensive grassland uncultivated in regions where the rainfall permits the production of even meagre subsistence crops. Developing the best land for crops is a direct consequence of high human population pressure and has negative effects on the use of the remainin land for grazing, including obstruction of traditional migration routes in zones of transhumance and denying access to watering points.

Most sub-humid or humid temperate grasslands have been converted to crop land by now, but are providing large quantities of forage and grazing from forage crops and sown pasture. Large scale conversion of drier grasslands to crops has had unfortunate results; the "dust bowl" of the Great Plains of the USA in the nineteen-twenties and thirties is notorious. In the mid twentieth century. Vast drylands were cultivated in the USSR, but crop production was unsustainable (Boonman and Mikhalev 2005), these lands are slowly reverting to grassland. Much rangeland in Africa is under subsistence crops and unlikely to be put back to grass, even at the drier margins. In the Brazilian Campos biome the 14.1 million hectares of natural grasslands in 1970 had fallen to 10.5 million ha as a result of cropping by 1996 (IBGE 1996).

Conversion brings rapid and high initial returns, based on good soil fertility which declines after a few years if the entire cropping system is not well managed. Loss of biodiversity, soil erosion, production decline, and water pollution are among the most severe consequences of conversion. Policy measures and regulations that protect sustainable use and maintenance of grasslands and their genetic resources are needed. Pastoralists and farmers must receive support by their local governments and by the international community for the sustainable management of grasslands in order to conciliate agricultural production and *in situ* maintenance of genetic resources.

The most sustainable way of maintaining thousands of grassland species that hold potential for many future uses and services, is to promote their *in situ* conservation by responsible and educated farmers and pastoralists. Grassland must be grazed and managed if it is to be conserved – it can not be enclosed and left undisturbed. If grassland is left ungrazed and undisturbed other vegetation will encroach and the grassland may be eliminated. Where precipitation is adequate invasion by woody species is likely. Neglected grassland will become scrub, thicket or forest according to its situation. Grassland plants are intolerant of shade and once overtopped will weaken and die out. Grazing prevents a build-up of senescent material, so keeping grassland plants in a vigorous state, removing the seedlings of palatable potential invaders and browsing helps control woody plants, keeps their branches above the browse line and opens up the vegetation for grazers. The involvement of herders or ranchers in any *in situ* conservation is therefore indispensable.

## 3.3 Interdependence and accessibility of sources of genetic resources

Many countries hold a significant amount of plant genetic diversity for food and agriculture in their gene banks, farmers' fields, and natural grasslands, but in the long-term, they are likely to require access to additional diversity from the species' centres of diversity. There is a continued need for exchange of plant genetic resources.

Today the free international exchange of tropical forage plant resources is more regulated than in the past few decades and governments of countries of origin are increasingly aware of the value and the importance of their indigenous genetic resources and are limiting their flow. Today there is an increased need to facilitate exchange of forage genetic resources to improve the quality and the diversity of genetic material available for food production and security and for sustainable agriculture and livestock production systems, particularly in developing countries.

The oldest examples of global dispersion of forage crops are alfalfa/lucerne (*Medicago sativa*) and berseem or Egyptian clover (*Trifolium alexandrinum*), which both originated in Asia Minor and northwestern Persia (Iran). The Persians took alfalfa to Greece in about 490 BC. It was introduced into Italy in the first Century AD and the Moors introduced it to Spain in the eighth Century AD. From there it went with the Spaniards to Mexico and South America. From Mexico it was taken into the southern USA and in 1854 it was taken to San Francisco from Chile (Westgate 1908). Berseem was of ancient cultivation in Egypt, whence it spread to India and southern Europe and eventually to the USA.

Annual medics (*Medicago* spp.) and subterranean clover (*Trifolium subterraneum*), from the Mediterranean basin were introduced to Mediterranean-type climatic areas of Australia, Chile, California, and South Africa. Their introduction, naturalization and diffusion had a remarkable impact on the new environments, particularly in Australia (Cocks 1999), where annual legumes have effectively contributed to sustaining and increasing cereal and animal production, being a basic component of ley and phase farming systems. Almost all commercial cultivars available in the market have been developed in Australia. Since the mid-1980s, more than 50 cultivars of annual legumes, mainly following germplasm collection, have been released in Australia for domestic use and export as seed.

White clover (*Trifolium repens*) is another example of interdependence of countries: according to Vavilov (1951) its centre of origin appears to be the Mediterranean region, but there are an estimated nine million hectares of pastures with white clover in New Zealand, five million ha in Australia and five million ha in the USA and it is widely distributed in southern Latin America and Europe. There is an annual world consumption of 8 000–10 000 tonnes of seed (Mather *et al*. 1996) and the New Zealand cultivar 'Grassland Huia', which has dominated the market for many years, is gradually being replaced by improved cultivars. White clover cultivars developed in the United Kingdom are multiplied in specialist seed growing areas in New Zealand and north-western USA (Barnes and Sheaffer 1995).

Collection trips of tropical pasture species and many national institutes have contributed to the material that has been stored and selected outside its country of origin by CSIRO, CIAT, EMBRAPA, ILRI and Biodiversity (formerly International Plant Genetic Resources Institute IPGRI). With severe downsizing of many forage seed banks and their selection programmes, today millions of hectares of cultivated pastures in the tropical world are at risk of being denied new, adapted cultivars. African grasslands represent the most important source of genetic material of grasses such as *Brachiaria*, *Pennisetum* and *Panicum* and Latin America of forage legumes and shrubs, such as *Stylosanthes* spp., *Arachis pintoi*, *Leucaena leucocephala*, *Gliricidia sepium* and *Cratylia argentea*. Therefore, international cooperation is needed to assure the good use and maintenance of tropical forages in the country of origin (especially important for *in situ* conservation), linked with research and selection programmes.

### 3.3.1 Mediterranean and temperate forage legumes

In the Mediterranean zone self reseeding annual grasses and legumes are important components of the ecosystem and agricultural production, originally in the context of traditional cereal-fallow rotations. Now many forage legumes are grown in a complex mosaic of environmental conditions and farming systems dominated by small ruminants (Porqueddu and Sulas 1998). Although perennial legumes have almost disappeared from the farming systems, there is renewed interest in some such as sulla (*Hedysarum coronarium*). There is a severe threat of loss of genetic diversity in parts of the Mediterranean basin where cereal production is being intensified; herbicide use on cereals threatens self-reseeding legumes.

*Trifolium hirtum* and *T. subterraneum* arrived in California (USA), in 1930, either via Australia or directly from Mediterranean countries. These clovers were adapted to the annual rangeland of California and had the potential to increase livestock production by improving forage quality and availability (Graves *et al*. 2001). Later, they were used as cover crops and have spread to several south-eastern States of the USA.

In Chile's Mediterranean-climate area, there are more than 7 000 000 hectares of pastures dominated by naturalized annuals from the Mediterranean basin and part of Eurasia. Despite their proven potential in increasing pasture production, particularly on infertile soils, the native forage legumes have been little explored and developed. Cultivars of subterranean clover and annual medics are imported from Australia, and perennial legumes from USA and New Zealand.

In the winter rainfall sub-regions of South Africa the decrease of productivity and sustainability of the legume component is a major problem, attributed to the use of cultivars selected for other environments. To find an alternative to wheat monoculture, the identification of new productive forage legume systems is required. Recently, a collaborative research project to develop a selection and screening programme for naturalized annual medics has been started (M.T. Oberholzer, pers. comm.).

Birdsfoot trefoil (*Lotus corniculatus*) sown in mixtures for grazing is a pioneer legume for marginal, infertile land. Nearly 800 000 ha are sown annually, in northeast USA, southeast Canada and southern Latin America (Blumenthal and McGraw 1999), but its use could be extended to other less-developed grassland regions. It has proved suitable for reclamation and revegetation of disturbed sites (Belesky 1999). Its drought resistance (Peterson *et al*. 1992) and tolerance of saline soils (Schachtman and Kelman 1991) are attributes capable of being more widely exploited. Certified seed of birdsfoot trefoil cultivars comprises the bulk of production in Canada (Beuselinck 1997).

### 3.3.2 Sub-tropical and tropical species

An FAO International Undertaking was held in Rome in October 2003 to restore free exchange of nominated species, so that plant breeders could exchange seed without fear that someone else will use the seed to develop cultivars and protect the resultant intellectual rights. An agreement was reached on a selected number of species, which are listed in Appendix 1 of the Treaty, but consensus could not be built around some important tropical species that today hold great potential for food production and security. This report contains, in Annexe 2, a list of important pasture species not mentioned in Annexe 1 of the Treaty; the Commission's guidance is sought on possible extension of Appendix 1.

In Brazil, 80 percent of cultivated pastures (80 million ha) are sown to *Brachiaria* spp. and *B. brizantha* cv. Marandu alone is estimated to cover 40 million hectares; the forage seed market value parallels that of hybrid maize. Considering that this grass is apomictic and therefore with no variation in its constitution, the risk for these production systems is very large. The ease of establishment, high animal production and ease of management have led this grass to become so popular in pasture systems. The rapid spread and adoption of a commercial cultivar of *B. decumbens* in countries such as the Philippines, and Australia should be carefully evaluated to avoid further risks of tropical world grassland monocultures. *Brachiaria* spp. are native to East and Central Africa where they are an important component of open grasslands (*B. decumbens*), moist savanna (*B. humidicola*), stream banks (*B. mutica*), and a pioneer species of cleared rain forest (*B. ruziziensis*).

## 4.GRASSLAND AND FORAGE GENETIC RESOURCES

There is continuing genetic erosion of forage species due to agricultural and urban encroachment and unsustainable grassland management, which has dramatic consequences at country and global level, given the role that these species could play for further generations. Since pasture crops are still in the process of domestication, natural grasslands are a major source of genetic material for breeding programmes. These grasslands are often maintained by pastoral societies who may have no involvement with the varieties bred from that material. Conservation programmes should be clearly focussed on preserving the many multi-functional characteristics of the different species.

*In situ* conservation through sustainable management should be deeply rooted in the culture and traditional farming systems of individual communities, but should also become the object of international goals and actions, to share the benefits and the burdens of sustainable use and conservation of genetic resources.

It is necessary to strengthen the economic support to research, breeding and maintenance of genetic resources in order to be prepared for extreme events such as climate change and desertification.

Fodder crops mostly have a longer history of domestication than pasture species but generally receive low priority in research and development in developing countries. Since fodders are mostly consumed on-farm information on areas and yields are usually vague. Because of their increasing importance in smallholder systems, fodders deserve more attention in the collection of locally adapted material, selection, breeding and development of seed supplies accessible to smallholders.

### 4.1 Pasture species selection and cultivar development

Sowing pasture is a modern practice which developed in Western Europe once farms were enclosedand the previous tumble-down fallow of the village system could be developed for fodder production. It is associated with large to medium scale farms. Field sizes have to be large enough to allow management of herds or flocks of grazing animals and generally require fencing and sometimes, water reticulation.

Selection and cultivar development of food crops date back to early times in agricultural history. With the exception of alfalfa (*Medicago sativa*) and a few temperate grasses and legumes, selection and cultivar development of forages is still in its infancy.

Selection, evaluation and cultivar development of forages has been undertaken by public and private organizations on several species that had commercial potential, namely, species of good nutritive value with a high yield potential, that responded well to fertilization and agricultural intensification that had also some desirable characteristics in terms of pest and frost resistance grazing tolerance and good competitive capacity.

#### 4.1.1 Temperate species

In temperate countries breeding and cultivar development of forages is well organized, often by the commercial sector, and breeding is tied in with seed production, certification and marketing.

Before the nineteen-sixties sown grassland in temperate regions mostly consisted of several grasses with white clover. Since then seed mixtures in western Europe have become simpler and even monospecific, often consisting of one or two cultivars of *Lolium perenne*. With a management regime of high N applications, intermittent grazing and cutting for conservation, swards in western Europe have tended to become near pure swards of *L. perenne, L. multiflorum* and *L. perenne* x *L. multiflorum* which comprise over 90 percent of grasses sown in north Western Europe (Humphreys and Theodourou 2001). Tetraploid ryegrasses were developed in the early. nineteen-sixties and at the time produced

8 - 15 percent higher yielding cultivars with higher digestibility, intake, palatability and water-soluble carbohydrates (WSC), milk production and rust resistance. Cultivars with 10 - 15 percent higher WSC gave increased milk yields with reduced urine-N levels. Higher contents of WSC contribute to reduced N and greenhouse gas emissions (methane and nitrous oxide N2O). DM yield of *L. perenne* cultivars had increased by 0.5 percent per annum over the previous 25 years in Western Europe. Well-managed swards of recently bred perennial ryegrass cultivars can produce 15 tons dry matter (DM) ha during a 6 months grazing season, whilst the latest cultivars can produce up to 25 tons DM ha, coming close to the maximum DM yields of perennial ryegrass in temperate regions of 29 tons dry matter ha (Cooper 1969). The United Kingdom, the Netherlands, Denmark and Belgium are the most active countries in temperate forage species breeding.

For many years *Trifolium* repens improvement was stagnant. Increased pressure to reduce N fertilizer use and the demand for more persistent cultivars led to more breeding. The UK has developed cultivars more compatible with grasses, with improved spring growth and winter hardiness, whilst tolerating moderate levels of N fertilizer.

Plant breeding for forage quality faces the problem of a relatively low heritability (30 percent ) of quality traits; in some cases improved quality has led to reduced dry matter yield. Techniques for genetic manipulation of forages have been developed and transgenic cultivars have been obtained by direct gene transfer to protoplasts, microprojectile bombardment, and Agrobacterium-mediated transformation.

Although forage from intensively managed grasslands is generally of high nutritive value, with high digestibility and CP level, DM intake is limited for high producing dairy cattle, for which there is no single factor or simple combination of factors that can be held responsible. Applications of molecular (DNA) marker analyses and technologies to forage crops have been slow, largely due to the complex polyploid nature of most perennial forage crops. Molecular linkage maps and marker-assisted selection will eventually become useful in selection and breeding programs. Molecular markers will certainly become one of the most important tools for identifying parents of hybrid forage cultivars and for grouping potential hybrid parents into heterotic groups (Quesenberry and Casler 2001).

## 4.1.2 Tropical species

Tropical forages are of very recent domestication. Germplasm testing with tropical forage plants spread from Africa to several tropical countries in the mid twentieth century, Australia (Eyles and Cameron 1985) and Hawaii (Hosaka and Ripperton 1944). Evaluation of tropical grasses and legumes in Queensland, followed by selection and release of species and development of cultivars began after 1950 by CSIRO and the Queensland Department of Primary Industries (Table 3). This was followed by CIAT in Colombia, EMBRAPA in Brazil, ILRI in Africa and ICARDA. Collection trips were made for grasses and legumes.

TABLE 3

**Numbers of grass and legume species and cultivars first used or released in Queensland, Australia ('t Mannetje 1984)**

| | > 1961 | 1961-1965 | 1966-1970 | 1971-1975 | 1976-1980 | Total |
|---|---|---|---|---|---|---|
| Grass cvs | 27 | 21 | 7 | 4 | 1 | 60 |
| "new" spp. | 20 | 7 | 3 | - | - | 30 |
| Legume cvs | 8 | 13 | 6 | 9 | 4 | 40 |
| "new" spp. | 8 | 7 | 1 | 4 | 1 | 21 |

Through its Tropical Pasture Programme, since 1971, CIAT has played a major role in collecting, maintaining, exchanging and evaluating forage germplasm, especially legumes, in tropical countries; through their programme and the International Tropical Pastures Evaluation Network (RIEPT), established with the participation of national institutions in Latin America, the adaptations of species and genera were determined. Accessions within these species and genera have been evaluated; cultivar releases may be through interaction with the private sector.

A long-term commitment by the institutions and the teams involved in tropical forage cultivar development is, hampered by reduced funding. EMBRAPA has an important programme on the selection and cultivar development of tropical pasture plants. In many developing countries forage cultivar development has a low priority and, even if locally selected ecotypes and cultivars are available, there are often problems of accessibility for smallholders since the production and distribution of seed and planting materials may lag behind research.

Ongoing work aims to develop cultivars which are productive, of high nutritional quality and tolerant to the prevailing pests and diseases, able to cope with low soil fertility and more 'farmer proof', i.e. resilient to improper management for a period of time as a result of droughts or failing markets.

### 4.1.3 Vegetatively propagated pasture grasses

Several tropical pasture grasses, grown on quite a large scale, are propagated vegetatively, usually in areas of reliable rainfall. They are usually stoloniferous and the most important are cultivars of Giant Star Grass *Cynodon aethiopicus*, *Cynodon nlemfuensis*, Pangola Grass *Digitaria eriantha* subsp. pentzii, formerly *D. decumbens* and Pará Grass *Brachiaria mutica*. These grasses, of African origin, have been used extensively in Latin America for many years.

A major limiting factors for tropical species is establishment, which is often poor because of poor seed quality. Seed quality of tropical grasses is often poor and this is exacerbated by severe seed quality decline due to storage at high temperatures and humidities. Poor seed is often a limiting factor in pasture establishment, hence vegetative propagation has many advantages, at least regionally.

## 4.2 Pasture seed and planting material

Seed production is essential for the distribution of forage species and cultivars. In industrialised countries it is done commercially. In pasture, herbage is the main product, flowering and seed production are detrimental to herbage quality. Pasture is mainly grown in climates suited to vegetative growth, but unsuitable for seed production. Seed rates are low, so transport of pasture seed over long distances is not a problem. Pasture seed production, therefore, has become concentrated in a few locations where microclimates and the availability of suitable skills are available, and also to obtain two harvests a year for temperate grasses. For humid temperate conditions New Zealand is a major producer; North America is a main producer of grass and lucerne seed Australia produces large quantities of seed of tropical and Mediterranean pasture species.

The greatest advances in forage legume and grass cultivar improvement and hence production of certified seed started in the early twentieth century. Government Seed Acts and stringent seed regulations followed and with the upsurge in plant breeding, seed production research and development of new technologies, average seed yields steadily improved. There is a need to produce 'breeder' or 'basic' seed by Government sponsored research institutes and commercial companies. Seed companies normally produce seed of forages that are widely grown and can be sold extensively nationally or exported. They are not keen on producing forages that are zone, or area,specific.

Tropical pasture seed production is important in Latin America, Australia and South-east Asia. Kenya was a pioneer in this field; the Kenya Seed Company, formed in 1956 to promote the use of improved pasture cultivars, developed by the National Agricultural Research Station at Kitale (Boonman 1993; Kenya Seed Company 2006) continues to produce forage seed. Producing tropical pasture seed is more difficult than with temperate and Mediterranean species. The plants are of more recent domestication and many cultivars are selections from the wild. They tend to have a long, spread-out flowering season making selection of an optimal harvest time difficult. Several tropical grasses have seeds with long awns or bristles which make cleaning difficult, as does their lightness: e. g. *Cenchrus ciliaris*, *Chloris gayana* and *Melinis minutiflora*.

In depth reviews of forages, temperate and tropical, are available through the FAOs Grassland Index (http://www.fao.org/ag/AGP/AGPC/doc/crops/4d.html)

Annexe 3 lists the main grasses and legumes for different climatic zones as defined by Troll (1966). Cook *et al*. (2005) have developed a SoFT database of tropical forages, which has identified many useful tropical grasses and legumes. (http://www.tropicalforages.info/).

### 4.2.1 Fodder crop seed

Many fodders are cultivars of annual field crops so their seed production is much less problematical than that of pasture grasses and legumes. Much is produced in the region where it is used and considerable amounts are grown on-farm. In developed countries fodder seed is part of agricultural trade.

### 4.2.2 Smallholder livestock producers and genetic material for different ecologies

Some forages, important for smallholders, or which have particular climatic adaptations, get little attention elsewhere. Some examples follow:

In developing countries fodder seed production is usually less well developed than that of other field crops and much of what comes to the market is of poor quality, dirty and of unknown variety – often that part of the harvest which the farmers did not need for their own use. Egypt produces high quality seed of *Trifolium alexandrinum*, some of which is exported, but in the irrigated lands of Western and Southern Asia supply of good fodder seed is often problematical. While research stations may have access to improved germplasm, or select in local material, there is a serious problem in bulking up research quantities to a scale where the crop can be commercially available. Part of the problem is conducting commercial production within governmental accounting systems.

#### Improved fodder cultivars and seed production in Pakistan

Workers in Pakistan had identified superior cultivars of oats and bred two improved cultivars of Trifolium alexandrinum and by the early nineteen-nineties these were well proven in the field – but seed supplies were very scarce. With assistance from an FAO TCP project local researchers organised commercial bulking of seed as well as a wide programme of demonstrations (Bhatti and Khan 1996). Once adequate quantities of seed were available, commercial producers took up seed production and oats are now a major winter crop in Pakistan (Dost 2004) and improved berseem is widely available.

#### Fodder oats in the Himalaya-Hindu Kush region

The success of oats as a winter fodder in Pakistan led to the Government of Nepal to request TCP assistance to develop the crop there since smallholders can no longer find wild forage in the forest and are now stall-feeding higher grade buffaloes. A range of germplasm was imported and screened over a range of altitudes. Farmers were enthusiastic. A seed production system was developed wherein government maintains foundation seed and bulking is done on contract by smallholders. This technology has been shared with neighbouring countries in the region. The main findings are given in Pariyar *et al*. (2005).

#### Cold-resistant Lucerne for the Xinjiang Altai

The Altai prefecture of Xinjiang region of China is arid to semi-arid but has the southern part of the Altai range (shared with Kazakhstan and Mongolia) as summer pasture. The Kazak herders gain their livelihood by transhumant pastoralism with multispecies herds of horses, sheep, cattle, goats and camels. Winter feed has always been the limiting factor. In the nineteen-eighties the Regional government installed large areas of irrigated fodder (mainly lucerne Medicago sativa) for hay production, in four-hectare family units. This was very successful (Li *et al*. 1996, Wang 2003) but was based on one local landrace. The climate is extreme continental with hot summers and very cold winters with little snow cover to protect crops. The first approach to widening the genetic base was through assembling "best bet" cold-resistant lucerne cultivars from northern Europe and North America. First year growth of the introductions was impressive: next spring only the local control plots survived; there was no quick solution through importation. With some FAO support the Regional Agricultural University undertook selection and breeding using local genetic resources and some Canadian material to produce cultivars with improved disease resistance and yield while retaining the cold tolerance of the landrace (Min 2003). Thereafter a TCP project assisted the Regional authorities to organise better seed production and distribution and to assure that seed was free of the Cuscuta parasite, a serious local problem.

### 4.2.3 Vegetatively propagated fodders

Large, perennial forage grasses such as *Pennisetum purpureum*, the larger types of *Panicum maximum* and *Tripsacum laxum* are generally propagated vegetatively and maintained as clones. They are well suited to smallholders who, once they have an initial stock, can provide their own planting material cheaply. Diseases can spread in clonal material so it is necessary for government institutions to monitor plant health, maintain clean mother stocks and, eventually, develop new cultivars. Vegetative material is difficult and costly to transport over long distances so local nurseries are necessary to start a cultivar; thereafter farmer-to farmer exchange usually operates. Other vegetatively propagated fodders include: sweet potato, edible canna and giant setaria.

**Napier Grass (*Pennisetum purpureum*) for smallholders in Kenya**

Napier Grass has long been grown at medium altitudes in Kenya, mainly for dairy cattle. There was considerable collection and importation of ecotypes during the nineteen-forties and nineteen fifties when Napier Grass was used in rotation with maize on large-scale farms. Since the nineteen-nineties it has become very important in smallholder dairy systems. It is vegetatively propagated with little new genetic material entering the system and problems have arisen. Head-smut caused by Ustilago kamerunensis spreads rapidly through infected planting material and smallholders report losses of 90 – 100 percent of their grass. A cultivar, Kakamega 1 has been identified as high yielding and resistant to head-smut. Napier grass stunting was first reported in 1997. Tests have confirmed that stunting is caused by a mycoplasma (Orodho 2005). Either new, resistant material is required or other species will have to be sought if smallholder dairying is to remain profitable.

## 4.3 Adoption of improved cultivars in animal production systems

Legume species and cultivars have been developed for most soil types and all except the driest climates in Australia (Oram 1990; 't Mannetje and Jones 1992; Cameron *et al*. 1993). Management techniques for sustainable pastures are reasonably well understood. The development of a cultivar does not ensure its adoption. Seed or planting material must be produced and an infrastructure is needed for quality control and distribution. Adequate information and demonstration, preferably involving the types of farm likely to use the material are necessary (Griffiths 1993). Seed merchants should be discouraged from overstating the adaptation and potentail value of their cultivars. There is large scale adoption of tropical grasses in Latin American countries and more recently in Southeast Asia.

Smallholders readily accept fodder crops if these are adapted to local conditions and production systems. Berseem, *Trifolium alexandrinum* became the main winter fodder of the Indo-Gangetic plain within twenty years of its introduction in the nineteen-twenties. The success of oats in Southern Asia in recent years is discussed above (4.2.2).

The technical, biological and socio-economic constraints that hamper adoption of legume-based pasture improvement can be summarised as follows.

### 4.3.1 Technical constraints

Intensive, large-scale forage cultivar development requires large inputs of scientific personnel, laboratory, glasshouse and field experiment facilities, limiting the involvement of many developing countries. In several countries there is active evaluation of cultivars and accessions, introduced from the large centres in Australia (CSIRO), Colombia (CIAT), Brazil (EMBRAPA) and Ethiopia/Kenya (ILRI).

Lack of commercial seed production and distribution at a reasonable price is a key reason for lack of adoption. Of three Australian and ten South American *Stylosanthes* cultivars released in South America, seed is available of only two - Mineirão (*S. guianensis* var. *vulgaris*) and Campo Grande (a mixture of *S. capitata* and *S. macrocephala*) (Shelton *et al*. 2005). In Bolivia, a seed company in Cochabamba has organized small farmers to produce seed, which is bought by the company, cleaned, packaged and marketed (Ferguson and Sauma 1993). Seed production and trade should be encouraged and policy makers and bankers should be educated about the possibilities and benefits of forage production improvement. Grassland scientists in developing countries are well aware of the need for forage seed production. Subsidies to encourage the development of an infrastructure for pasture improvement and assist farmers in the adoption of proven technology in developing countries could contribute immensely to increase food production and more sustainable land management. Alhassan and Barnes (1993) advocated loans in kind (materials, seeds, fertilizers) for Ghana. The success of such policies for smallholders has been demonstrated in Thailand with seed production (Manidool 1990; Phaikaew *et al*. 1993) and in Vanuatu with beef production (Macfarlane *et al*. 1993).

## 4.3.2 Socio-economic conditions for forage improvement

Socio-economic factors are the main causes influencing adoption of new pasture technology; technologies are available that suit a range of input levels. The adoption of pasture improvement in existing farm systems is governed by the following criteria ('t Mannetje 1993): land tenure; suitability of forage in the farming system, including rotations; the demand for improved animal production; profitability and the motivation of producers.

**The demand for improved animal products.** Demand for food is increasing through rising population and purchasing power in many developing countries, leading to a greater demand for food of animal origin. Meat and milk consumption has increased three times as fast in developing as in developed countries since the 1980s. Meat consumption in kilograms per head in developing countries has increased from 14 in 1983 to 29 in 2003 and milk consumption from 35 to 45. Equivalent figures for developed countries are 74 and 82 for meat and 195 and 202 for milk. Part of the increased demand will be met from ruminant production; monogastrics, mainly production of pork and poultry products is also increasing. The energy contribution of meat, milk and eggs to the human diet, only 10 percent, accounted for only half the requirements (Delgado 2005).

TABLE 4

**Projected trends in production of selected livestock products (after Wright, 2005)**

| | Developed world million ton | | Developing million ton | |
|---|---|---|---|---|
| | 1993 | 2020 | 1993 | 2020 |
| Beef | 35 | 38 | 22 | 44 |
| Milk | 348 | 371 | 164 | 401 |

Meat and milk production from grass-based systems is reviewed by Wright (2005). Only about 9 percent of meat is from grazing systems based almost entirely on natural grassland with little or no integration with crops – mainly pastoral systems. Mixed farming systems account for 54 percent of meat production and 90 percent of milk. A considerable part of the feed consumed by livestock in mixed systems is from grazed or stall-fed pasture. In New Zealand nearly all milk production is grassbased with over 90 percent of milk production based on pasture. In the European Union 95 percent of milk production is grass-based with grazing supplying 70 percent of nutrients; 75 – 100 percent of requirements in most beef and sheep systems can be met from grazed or conserved grass. In order to increase animal production for meat, milk, draught and manure, the feed supply must be improved, i.e. forage production and quality need to be increased. Recent trends in livestock production are discussed in detail in the FAO study World agriculture towards 2030/2050 (Alexandratos *et al*. 2006).

What livestock are raised and which product is most important is partly the choice of the stock raiser but is influenced by local conditions. Extreme climates limit species choice: the tundra supports reindeer; yaks thrive in cold, high altitude sites in Asia and camelids are raised in the highest Andean pastures. In Eurasia Arabian camels are raised in hot arid zones and Bactrian camels in cold ones. In general sheep and cattle prefer open, grassy pastures while goats like browse. High quality pasture is required for dairying and fattening, poorer ones suit breeding and fibre production; the nutritional requirements for wool production by adult animals are low. Buffaloes are restricted to areas of mild winters; dairy types are largely associated with stall feeding in irrigated areas. There is a wide range of breeds, especially of sheep and cattle for different products and with different ecological adaptations. Cultural attitudes influence livestock choice. India has 185 000 000 cattle (FAOSTAT 2007) kept for milk, draught and dung, but hardly any beef is eaten there. Pork and poultry meat are the most popular in Southeast Asia, but no pork is produced or eaten in Muslim countries.

**The value and marketability of animal products.** Attractive economic returns, comparing favourably with ranching, can be achieved by traditional livestock husbandry in developing countries, producing saleable products, draught power and manure (Scoones 1992). Many traditional herders commercialise live animals but most retain dairy products for domestic use. Access to markets may, however, be a problem in the more isolated grasslands.

In many developing countries smallholders, increasingly, integrate livestock into production patterns, often commercialising crop residues through ruminants. Where market conditions are suitable smallholders grow fodder to supplement other roughages. This is increasing in several zones and fodder is fed to monogastrics and fish as well as to ruminants. (see 2.7.2)

Stocking rates of rangeland, particularly near populated centres, often exceed carrying capacity, thus reducing productivity. Animal products other than meat and milk, although valuable, often have no market value, e.g. draught power and dung. Subsistence producers are unlikely to have finance for pasture improvement, even if other restrictions, such as land tenure, do not apply.

Commercial producers must market their outputs. Prices on local, national and international markets are determined by supply and demand. Local demand depends on consumers' incomes. In most developing countries, prices for animal products tend to be low and there is little incentive to invest in pasture improvement.

### 4.3.3 Promoting public awareness of the value of plant genetic resources for food and agriculture; conservation and use

An increasing demand for meat and milk is likely to be met by the intensification of pasture-based systems and forage crops, but requires cooperation of governments, industries, farmers, communities, researchers, and consumers in order to be sustainably developed. It is hoped that this document will be used as a first step to promote *in situ* conservation and sustainable use of forages and grassland species for future generations through a collective effort of member countries.

## 4.4 Pastoralists and grassland species

Since tropical pasture species are still in the process of domestication, natural grasslands in tropical and semi-arid regions are a major source of genetic material for selection programmes. These are used by pastoralists who have no involvement with the cultivars developed from that material. There are no international regulations or agreements concerning the use and maintenance of these species, which are often the base of sustainable livestock production systems and livelihood of pastoralists. Much genetic material maintained in grasslands holds potential for production under difficult conditions.

## 4.5 Documentation and monitoring

A large number of countries reported for the First State of the World's plant genetic resources for food and agriculture, a lack of information about indigenous genetic resources, and a lack of well documented inventories of forage species. There is a need to assess grassland species diversity at species and gene level (some examples in Harris 2000); some information on inventories of existing collections are available from the holders (e.g. CIAT online) and globally through the System-wide Information Network for Genetic Resources (SINGER) for planning and allocating priorities to collection and conservation activities.

Despite the worldwide economic relevance of grasslands, few programmes have promoted strong action to meet effective and efficient genetic resource management for forage species and they are often insufficiently connected. The information related to *ex situ* collections concerning the biological status (whether wild, old cultivar, landrace, selection, hybrid or introduction) is not adequately documented.

In order to assure the availability of information related to tropical forage genetic resources international efforts should be undertaken to renew investments into organizing and updating international databases related to cultivated species and to develop information sharing tools. Monitoring systems of the state of genetic erosion of wild germplasm should also be promoted through international cooperation and alliances between the public and private sectors.

# 5. GENETIC RESOURCE CONSERVATION

## 5.1 Genetic erosion

FAO Country Reports indicate that recent losses of diversity have been large and that erosion continues. Gene complexes and species can be lost and become extinct, but cultivars can also disappear. Cultivars may disappear without a corresponding loss in genetic diversity, but cultivars as unique combinations of genes can have immediate utility. The loss of forage, pasture and grassland diversity cannot be estimated since there is no inventory.

The chief cause of loss of genetic diversity has been poor grassland management, overgrazing, and spread of modern, commercial agriculture. The consequence of the introduction of new cultivars of crops and forages has been the replacement – and loss – of highly variable pastoral ecotypes and natural cultivars.

There is a solid link between cultural and biological diversity. The loss of genetic diversity is frequently associated with the loss of knowledge about this material. Very little information available is related to pastoral knowledge of forage and grassland species, their management and multiple uses.

The condition of the surviving extensive areas of grassland is often poor, probably due to mismanagement, but partly also to climatic factors. Commercially managed extensive grasslands are not necessarily in a better state than traditionally managed land. There is little or no historical record of grassland condition, so the degree of degradation can not be determined. Many countries lack an inventory of grasslands, their condition and biodiversity and systematic information on grassland and forage species. Worldwide, efforts are needed to assess, inventory, monitor and document the national heritage of grassland and forage species genetic resources. There is a serious need for *in situ* conservation of pasture genetic resources on such lands.

Many of the grasslands which were colonised and exploited for livestock production in the past two centuries are in a very poor state; they often degraded rapidly in a short period usually through overgrazing as a result of over-optimistic estimates of carrying capacity of these grasslands which had not previously been heavily grazed by domestic ruminants. (Suttie *et al*. 2005).

> The grasslands of Patagonia started to deteriorate within fifty years of their development as sheep runs (Borelli and Cibils 2005). In Australia there are management problems in all pasture zones and high grazing pressure has led to replacement of palatable species by those that avoid high grazing pressure by their fibrous, unpalatable or ephemeral nature; bush encroachment is also a problem (Mc Ivor 2005; Kemp and Michalk 2005).

Eurasian grasslands were probably in a stable balance with the herds of pastoral peoples over many centuries, but political changes in the twentieth century upset that balance in many areas. The grazing lands of the former USSR were "scientifically" managed throughout the collective period but employees of state and collective farms were allowed to graze privately owned stock on the same pastures, leading to overgrazing and their condition deteriorated seriously (Boonman and Mikhalev 2005). The grasslands of the Central Asian countries are also in a poor state (Gintzburger *et al*. 2003). Those countries generally introduced higher-yielding but more demanding livestock as well as bringing in winter feed, thus increasing pressure on the grassland. Under a market economy these systems collapsed. The semi-arid grazing lands of North Africa and Western Asia were under tribal control until the end of colonial times. Large areas of grazing land were only accessible after the autumn rains and herds had to leave once surface water ran out, so the grasslands were rested for a long period of the year. There was no external feed so stock numbers were limited to what could be carried through the lean season on available pastures and water. There was no rainfed cropping on marginal lands. They deteriorated very seriously when tribal authority was abolished, grazing systems broke down and purchased cereals, some subsidized and transported water made the land accessible for most of the year (Suttie *et al*. 2005).

Mongolian grasslands, although seriously stressed, are generally less degraded than elsewhere in the region since, during the collective period, they continued to use local, hardy breeds and followed a mobile production system; after decollectivisation stock numbers rose (Suttie *et al*. 2005). China took a different approach after decollectivisation and allocated small portions of semi-arid grazing to families or family groups, thus seriously limiting their possibilities of mobility. China's grazing lands are now very seriously degraded (Hu and Zhang 2003).

Because of the large number of existing grassland species and high cost of maintenance of gene banks, the best way to assure their safe conservation is through the promotion of global efforts and agreements that promote the sustainable use of natural grassland by local pastoralist and farmers, their associations, local governments, the international community and the private sector.

## 5.2 Gene banks

Global gene banks are refrigerated buildings for long term seed storage of wild relatives of grassland species for future use, breeding material and seed resources. Gene banks also hold breeding lines and valuable cultivars that do not occur in the wild and might be lost. As seeds eventually lose their viability all species must be grown at intervals in the field to collect fresh seeds. Gene banks receive very little government support around the world and are in danger of being unable to continue their important function, or even to disappear. This is contrary to the Convention on Biological Diversity signed by all the Member States at the United Nations Conference on Environment and Development in Rio de Janeiro from 3 to 14 June 1992.

Most temperate countries have forage gene banks and commercial breeding companies hold their own breeding material in cold storage and in field plots.

Maass and Pengelly (2001) wrote "After very active years of pasture and forage research at major institutes, interest in tropical forage genetic resources has drastically declined. Apparently, the early phases of collecting and evaluation were much more valued than conserving and keeping the germplasm available for future generations. Accumulated data are not easily accessible and knowledge of tropical forage genetic resources is progressively being lost. This worldwide decrease in activity and loss of knowledge is due to declining resources. It is suggested that a global database on tropical forage genetic resources should be established and also that finances be made available to at least maintain collections at their current reduced level".

It is essential that, in most institutions where tropical pasture evaluations have taken place, continuity be given to the complete process from evaluation to release. Selected accessions need to be evaluated in regional trials, under grazing, then officially released, with an adequate supply of seed and a strong marketing strategy. With the presently available germplasm and cultivars it is as important to foster their adoption as to extend further collection, except for targeted species.

The three main international tropical forage gene banks in the world together hold around 30 000 accessions of the principal forage species (Hanson and Maass 1999). Collection of forages was prioritised in the 1970s and 1980s by CSIRO, CIAT, ILRI and Biodiversity, with the collaboration of many national institutes (Schultze-Kraft *et al*. 1993; Hanson and Maass 1999). The main focus was on tropical legumes. At CIAT, in 1996, 89.2 percent of the specimens were legumes and 9.8 percent were grasses (Torres 1996). The main genera in the banks are 22 legumes, 12 grasses and 14 shrubs, whose number of species and accessions are summarized in Table 5.

TABLE 5
**Number of species (and accessions) of the main genera of legumes, grasses and shrubs in the three main international gene banks**

| | CIAT | CSIRO | ILRI |
|---|---|---|---|
| Legumes | 345 (15 980) | 518 (9 210) | 233 (4 550) |
| Grasses | 105 (1 880) | 252 (2 670) | 139 (1 820) |
| Shrubs | 66 (720) | 154 (1 420) | 183 (1 450) |

SOURCE: Adapted from Hanson and Maass (1999).

It is estimated that accessions in these gene banks are 30 percent duplicated and may be repeated in national gene banks (Hanson and Maass 1999). Stored legume seeds may show variation in different gene banks after renewal because of cross-pollination in species originally thought to reproduce by autogamy (Hanson and Maass 1999).

From 1986 to 1991, CIAT evaluated more than 1 000 grasses in Colombia, 400 in Brazil, 270 in Peru and 430 in Costa Rica, respectively, and 1 000 herbaceous legumes in the Llanos in Colombia, 1 100 in the Cerrados in Brazil, 640 in the humid tropics in Peru and 430 in the humid sub-humid tropics of Costa Rica (Miles and Lapointe 1992). Altogether, in Brazil, 343 *Brachiaria* and 42 *Paspalum* accessions were evaluated. Of the legumes, 393 *Centrosema*, 234 *Desmodium*, 37 *Arachis*, 47 *Pueraria*, 225 *Stylosanthes*, 215 *Calopogonium* and 15 *Cajanus* accessions and a few from other genera were evaluated (Pizarro and Carvalho 1992).

There are problems with the maintenance and further development of international tropical forage gene banks. At present only the CGIAR institutes ILRI and CIAT hold significant numbers of species in long term storage that are available for international exchange. CSIRO in Brisbane, had such a gene bank (Tropical Forage Genetic Resource Centre, ATFGRC), but at the demise of the CSIRO Division of Tropical Agriculture, the Australian Tropical Forage Genetic Resource Centre (ATFGRC) had to send around 15 000 accessions to CIAT and the International Livestock Research Institute (ILRI) for storage due to downsizing of its operations (Maass and Pengelly 2001) with a selection of the "more important" genera still being held by the Queensland Department of Primary Industries ATCGRC in order to ensure that valuable germplasm would remain in Australia, so that it would not have to be imported and quarantined again when the need to import it might arise. This seed is not readily available internationally.

## 5.3 Wild and native species and in situ conservation of forage genetic resources

Many wild grassland species are not yet in gene banks; they remain widespread in low-input grasslands around the world and their contribution to animal feeding is important. Conserving species biodiversity permits the conservation of a genetic heritage that might be necessary for future livestock production systems.

The condition of natural grasslands is a serious issue for *in situ* conservation. They are everywhere degraded, often seriously. This means that, in a large part of the world and for much of the genetic base, *in situ* conservation is problematic. Land pressures are increasing, and unless there is a massive international determination to conserve grassland areas, there may be limited value in *in situ* conservation in large parts of the world in twenty years from now.

Traditionally, the main emphasis of *in situ* conservation programmes related to grassland has been on the sites valued for their wildlife or ecological value. While *in situ* conservation is common for wildlife and forest genetic resources, there is potential to use *in situ* approaches for the conservation of genetic resources of forage crops and grassland species. During the preparatory process for the International Technical Conference, the lack of integrated conservation strategies for PGRFA, based on the complementarity of *in situ* and *ex situ* approaches, was noted and there were proposals for increased allocation of resources for *in situ* conservation, especially in developing countries. The need to develop several different *in situ* approaches to PGRFA was identified during the preparatory process: specific conservation measures for wild relatives of crops and wild food plants, particularly in protected areas; sustainable management of grazing lands, forests and other managed resource areas; conservation of landraces or traditional crop cultivars on-farm; and in home gardens.

Given the importance of wild species of cereals, crops and grassland plants in the livelihood of poor communities and pastoralists, and the importance that many grasses and legumes hold for livestock production and stress adaptation, additional efforts should be made to address their conservation. The floristic composition of grasslands depends on their management, the presence of grazing animals, often controlled burning as well as climate and soil so *in situ* conservation must take this into account and the grazing community must be part of the process. This means that pastoralists (or ranchers) must participate in the planning and management from the outset.

Most plant genetic resources of importance for food and agriculture are found outside existing protected areas, in ecosystems such as farms, grasslands, forests, and other managed resource areas, many of which are common property. The main grasslands of the world have been managed for centuries by pastoral communities, to maintain their capacity for livestock production and for the provision of food, energy and fibres. PGRFA in these ecosystems are not just being conserved, but are being managed and developed. Due attention will thus need to be paid to both conservation and productivity questions, and to associated economic and social constraints. Grasslands, for example, are very often subject to overgrazing and other degrading factors. Several countries in West Africa, nevertheless, reported on the important role of local communities using traditional methods in the sustainable management of ecosystems.

## 5.4 Balance and complementarity of in situ and ex situ conservation

Most *ex situ* gene banks maintain genetic material of food crops; only a few deal with forage crops and grassland species because the domestication of grassland species is recent compared to the domestication of crops and the forage seed traded is much less than that of food crops. Ensuring the safe *in situ* conservation of grassland genetic resources through international cooperation and a set of activities such as capacity building and the support to the rural communities which maintain and manage these resources, is of utmost importance. The role and importance of *in situ* conservation is widely accepted for wildlife, fisheries and forest genetic resources, and the experience gained in these sectors could be a useful base for promoting *in situ* approaches for genetic resources of grassland species.

## 5.5 Monitoring of genetic resources

International cooperation is necessary for efficient monitoring of forage crops, pasture and grassland genetic resources and their use, management and maintenance by farmers and pastoralists, but Governments need to be made aware of the need to engage in *in situ* and *ex situ* conservation programmes. Successful cooperation would depend on government investments and international cooperation in the conservation of genetic resources, otherwise effort spent in collecting and multiplication is futile. There is reason for concern, as government restrictions are affecting institutions such as the CSIRO, and CIAT, also affecting collection. Budget restrictions have cut back CIAT's staff and consequently its scope for action in Latin America and its global activities for humid and sub-humid environments, with a focus on situations with biotic and abiotic stresses, i.e. the conditions of many smallholders. The Tropical Pastures Programme at CIAT had 22 scientists and staff in 1984, but only 4–5 in 1997.

## 5.6 On- farm management of fodder crops, pasture and grassland genetic resources

In many countries, farmers practice de facto conservation of genetic diversity by maintaining traditional landraces. Farmers and pastoralists engage in resource management in many different ways. Many exchange forage vegetative material, contributing to the maintenance at local level. Such farmers typically have limited financial resources and farm on marginal lands. Access to appropriate, scientifically developed improved cultivars may be limited, which is why they are substantially selfreliant in terms of seed. Over one billion people live in farm families, where the responsibility for management and improvement of PGRFA, including forage crops, currently lies with the family itself. On-farm management of PGRFA, and in particular of grassland and forage crops, is poorly documented. Its effectiveness is not well known in terms of maintaining genes and genetic combinations, or in terms of its cost-effectiveness. Specific studies have been initiated to support and develop "on-farm" management, conservation and improvement of grassland and forage crop genetic resources. These projects draw upon recent academic studies calling attention to the sophistication of the indigenous knowledge and the effectiveness of many traditional practices in conserving and developing PGRFA (Schareika 2003).

The Australian Centre for International Agricultural Research (ACIAR), in cooperation with Armenian and Russian scientists, is presently undertaking a collection of seeds of ancient crops, landraces, and wild ancestors of crops, such as wheat, barley, lentils, chickpeas, faba beans, field peas, vegetables and pasture legumes that have been grown by small farmers in remote areas of Central Asia and the Caucasus for centuries. The seeds will be stored in the genebanks of The Armenian Institute of Botany, the Vavilov Institute of St. Petersburg in Russia and ICARDA. Some 4 000 unique samples from a great diversity of environments have so far been collected (Collis 2006).

# 6.USE, PRODUCTIVITY AND MANAGEMENT OF GRASSLAND AND FORAGE GENETIC RESOURCES

## 6.1 Extensive grazing systems

Extensive grazing lands are great reservoirs of biodiversity and genetic resources. Grazing is essential for the maintenance of these ecosystems and their biodiversity and livestock production is part of the ecosystem. Their sustainable management is of paramount importance for the maintenance of plant genetic resources and their successful *in situ* conservation.

Detailed information on the forage resources and grazing systems of over eighty (mainly developing and transition) countries is given in the Country Pasture Profiles on the FAO AGPC website at http://www.fao.org/ag/AGP/AGPC/doc/Counprof/regions/index.htm.

### 6.1.1 Commercial extensive grazing systems

Commercial grazing of rangeland (ranching), is large-scale and commonly involves a single species, usually beef cattle or sheep mainly for wool production. Some of the largest areas of extensive commercial grazing grew up in the nineteenth century on land which had not previously been heavily grazed by ruminants in the Americas and Australasia and to a much lesser degree in Southern and East Africa.

Choice of animal species and breed is in part determined by the grazing resources and the climate and by the product desired, but in commercial systems market requirements are central and, on extensive grazing, beef cattle and sheep predominate. In warmer climates zebus or zebu cross bred cattle, often developed locally, became increasingly popular.

In commercial systems management aims at improving animal status and production per animal. Common management practices to that end include: dividing herds into categories so that they get the appropriate treatment, avoid under-age and unseasonable breeding, controlling parasites and predators, providing veterinary care and using and maintaining breeds which suit the climate and the condition of the land and potential markets. Ranches are often fenced to allow herd division and in some cases rotational grazing or seasonal resting of part of the grassland. Stock raised on ranches is often finished elsewhere.

### 6.1.2 Traditional grassland systems

Settled communities use natural grazing near their crop land but the wide grasslands are exploited by pastoralists in mobile systems. These systems, which are important in the drier parts of Africa and Asia, are oriented to subsistence production and risk-mitigation since livestock rearing in areas of unreliable climate is always exposed to risk. Traditional herders raise several species and generate several products. Many herders commercialise live animals but most retain dairy products for domestic use.

Non-commercial, extensive grasslands of the world are managed by traditional, often mobile grazing systems; the maintenance of these systems is vital for the *in situ* conservation of pastoral species (and biodiversity in general).

### 6.1.3 Mobile grazing systems

The terms "nomadism" and "transhumance" are sometimes used indiscriminately : nomadism is used of pastoral groups which have no fixed base, but follow erratic rain storms; transhumance describes systems where people with their animals move between distinct seasonal pasture areas, usually at considerable distance or altitude from each other. They occur in Africa, Asia (Suttie and Reynolds, 2003) and in southern Europe. Mobile herders keep mixed flocks; this helps reduce herding risk as well as making a fuller use of the vegetation on offer – the various species and categories may be herded separately. Multispecies herds may make more efficient use of grazing resources than monospecific grazing, for example goats, horses and camels make better use of shrubs than do cattle or sheep; pasture condition may be better maintained if several species are involved and multiple species may also reduce risk. Traditional systems, while selling livestock and livestock products, are designed primarily to provide subsistence and security to the herders.

Traditional livestock production systems vary according to climate and the overall farming systems of the area. They use a wide range of livestock since, (in addition to cattle and sheep) buffaloes, asses, goats, horses, yak and camels are predominantly raised in the traditional sector. Livestock, raised for subsistence and savings, are usually multi-purpose, providing meat, milk, draught, fibres, manure and often fuel. In traditional mobile systems herds move between grazing areas according to season; some move according to temperature, others on feed availability. Other factors may affect migratory movements, such as biting insects (Erdenebaatar 2003). The commoner types of mobile system in Asia are described in Suttie and Reynolds (2003) and the problems facing traditional mobile systems in Africa are discussed by Niamir-Fuller (1999). These traditional pastures are major sites of *in situ* conservation of genetic resources of forage and other plants.

In sub-Saharan Africa many herders keep cattle, sheep and goats but in the drier areas small stock, or camels and small stock, are kept. In North Africa and Western Asia small stock and camels were general in extensive herding but with the increasing popularity of motor transport camels are much less common. In India and Pakistan buffalo are herded but herding groups tend to keep a narrow range of stock and either specialise in small or large ruminants. In much of Central Asia and Mongolia herding involves "the five animals" – horses, camels, cattle, sheep and goats.

## 6.2 Mixed farming systems and rotations

Pastures may be sown or overseeded in a grazing system with the aim to have improved permanent pasture or may be sown as a ley within a mixed farming system with a duration of one to three or four years within a crop rotation. Mixed farming systems have the potential to be among the most efficient ruminant production systems since they allow an efficient use of resources by integrating crop and livestock production to maintain soil fertility and biodiversity while utilising crop wastes.

Whilst fertilization is necessary on most soils, high rates of N fertilizer application on pastures with ensuing nutrient surpluses has given rise to pollution through nitrate leaching. This has led to nutrient control measures being applied to farms in the European Union and the USA. Use of grass-legume mixtures is likely to mitigate this pollution and adapted cultivars will continue to be required.

The fertility-building and weed and disease control qualities of a pasture break in a rotation have been recognized for a long time. All grassy vegetation favours the organic matter content of soils as well as the development of decomposition organisms. Earthworm populations are much greater under grassland than in arable land. An earthworm biomass of 1 000 – 5 000 kg ha-1 can be found in grassland compared to less than 500 kg $ha^{-1}$ under crop (Granval *et al*. 2000). This quantity is greater in grazed than in mown grassland.

In Africa the more fertile and arable grazing lands are used for cropping and livestock production is relegated to poorer, less productive areas. One way of improving livestock production would be to produce more good quality forage within the existing crop-livestock systems. In sub-Saharan Africa much research has been carried out on multiple cropping, i.e. growing two or more crops on the same field in a year. Forage legumes can be grown together with cash or food crops. The legume and the crop can be grown simultaneously on the same field or sequentially, either in the same year or in following years.

Meat and milk production from grass-based systems is reviewed by Wright (2005). Only about 9 percent of meat production is derived from grazing systems based almost entirely on natural grassland with little or no integration with crops – mainly pastoral systems. Mixed farming systems account for 54 percent of meat production and 90 percent of milk production. A considerable part of the feed consumed by livestock in mixed systems is from grazed or stall-fed pasture.

### 6.2.2 Intensive grassland production in north-western Europe (Wilkins 2000)

Grassland production improvement research and practice received special emphasis in north West Europe immediately after the Second World War when there were food shortages and widespread poverty in rural areas (Thornton *et al*. 2002). Intensive dairy systems using high levels of N fertilizer and imported concentrates remained the dominant form of production until the 1980s. Research aiming at higher production levels was stimulated by government funding for regional and infrastructural improvements and extension services. Production per cow, per hectare and per unit of labour rose continuously. The increased output of dairy products was subsidized and farmers had no concerns about markets or environmental consequences. Total dairy and meat production increased to such an extent that Western Europe changed from a net importer to a net exporter of animal products. The production of cows' milk in Western Europe, increased from about 90 million tons in 1950 to about 170 million tons in 1980. After the introduction of the milk quota system in 1984, milk production declined to about 165 million tons in 1990 (FAO 1962, 1981, 1991). The EC and national policies regarding the pricing of agricultural products and subsidies were maintained for a while, even after production greatly exceeded the demand of European and export markets for the ever-increasing amounts of agricultural products. Eventually, the EU was no longer prepared to accept the very high costs associated with this. Furthermore, the efficiency of N in these intensive production systems was very low (ca. 16 percent). This led to unacceptable emissions of NH3 (volatilisation), NO3 (leaching) and N2O (denitrification and nitrification) (Van der Meer and Wedin 1990).

## 6.3 Organic pasture production systems

Pasture and forage crops are an important part of organic farming both for livestock production and for soil fertility maintenance in arable and mixed farming systems. The principles of organic farming as they concern forage and pasture have been discussed by Younie and Baars (2005):

- only fertilizers from approved lists are permitted; these are usually either manures or mineral fertilizers such as lime and rock phosphate which are slowly soluble in the soil;

- soluble mineral fertilizers, which includes all the nitrogenous fertilizers, are forbidden;
- manure supply to crops must be based on a balanced rotation, including legumes, and effective nutrient cycling systems within the farm;
- the use of genetically modified organisms is forbidden as is the use of meat-meal;
- herbicides are not permitted.

Organic farming, puts a great emphasis on the use of forage and grain legumes and, if it expands, more legume cultivars suited to the restrictions placed on their nutrition imposed by the system, may be needed. In some livestock-free organic systems, legumes are grown for ploughing under as part of fertility-building and weed control.

In recent years, there has been an exponential increase in the implementation of organic agriculture in Mediterranean areas of Europe, with about 60 000 farms and one million hectares of agricultural land in Italy.

## 6.4 Cut and carry systems

The integration of fodders into smallholder mixed farming systems is likely to continue as free grazing disappears and more productive stock are kept under stall feeding.

## 6.5 Legume-based pasture improvement

Grasses and legumes have been in use for pasture improvement by farmers in temperate regions since Roman times, and legume-based pastures (notably using *Trifolium repens*) developed in Europe from the eighteenth century as farmland was enclosed and modern rotations brought into use. They continued to be a mainstay of fertility-building and livestock feed production until the advent of cheap nitrogenous fertilisers in the mid twentieth century.

Grasses and legumes for tropical and sub-tropical climates have been under serious consideration for pasture improvement only since about the 1950s.

The philosophy on which pasture improvement research and development in tropical and sub-tropical Australia was based can be summarized as follows (Davies and Shaw 1963; Shaw and Bryan 1976):

- unimproved native grasslands are deficient in productivity because of the nature of their species, which have evolved strategies to survive under conditions of low nutrient levels and unreliable erratic rainfall in which high productivity is not an ecological advantage; the species develop rapidly after the first rains following the cooler dry season during which they are dormant, and come to flower within weeks after the start of regrowth; they have low DM yields, low CP concentrations and low digestibility;
- the best ways to overcome these problems are to replace the native species by productive and persistent grasses and legumes, or by oversowing a legume into the native grassland; where necessary and economically feasible nutrient deficiencies should be overcome by the use of non-N fertilizer, or species should be used that have lower nutrient requirements;
- pasture management should aim to optimise animal production and maximize persistence of the pasture species;
- pasture research for development is expensive and should be restricted to regions of adequate rainfall (i.e. above 650 mm per annum with a growing period of no less than 5 months) to make it potentially profitable

The research activities used to achieve these goals were:

- an integrated approach to pasture improvement in the sense that research was not aimed at a particular narrow aspect of grassland science, but at the whole production system, consisting of the complex of soil, plants, animals, their interactions with each other and with the environment, as influenced by management (fertilization, grazing, cutting) in relation to DM production, botanical composition, nutritive value and animal production;
- plant introduction for an improved germplasm base, mainly from East Africa (most grasses) and South America (most legumes) with regional on-farm evaluation studies to test for adaptability to climate and soils;
- studies of N-fixing bacteria for efficient nodulation and N-fixation of legumes;
- plant nutrition studies on mineral deficiencies and to develop fertilizer recommendations;
- phytochemistry to study plant toxicity of introduced species;
- plant physiology to study growth and the effects of stress;

- plant genetics to study breeding systems and carry out plant breeding to improve mainly pest and disease resistance;
- animal nutrition to test nutritive values;
- pasture agronomy and ecology for pasture and grazing management.

This was in sharp contrast to the approach adopted in southern Africa which was strongly influenced by the concept that the climax or sub-climax vegetation suitable for grazing of the veldt should be maintained. Within this context native grassland management studies (grazing, spelling, burning) were undertaken to bring about desired changes in botanical composition (Scott 1947). Although this has led to some improvement in forage utilization, very few results on increased animal production have been published.

Australian research and development of tropical pastures had an impact on pasture development in northern Australia, tropical America, Southeast Asia and the Pacific Islands. Since 1961, some 70 grass and legume cultivars were released in northern Australia (Eyles and Cameron 1985). Many early cultivars were not widely adopted because they required fertilizer inputs and had major deficiencies in terms of grazing intolerance, lack of persistence and susceptibility to pests and diseases. Susceptible cultivars were replaced by new cultivars with the desired properties. Cultivars are now available of *Stylosanthes* spp. tolerant to anthracnose (Cameron *et al*. 1993) that can grow on soil with low P status and low pH, a rust tolerant cultivar of *Macroptilium atropurpureum* (Bray 1988) and cultivars of *Arachis pintoi*, *Vigna parkeri*, *Chamaecrista rotundifolia* and *Desmodium ovalifolium* that can tolerate heavy grazing (Cameron *et al*. 1989). The psyllid epidemic that caused leaf losses in *Leucaena leucocephala* has been curtailed by predators that have increased as a result of the epidemic (Oka and Bahagiawati 1988). However, the severe psyllid damage reported in other countries in the Pacific region has not occurred in northern Australia (Queensland Department of Primary Industries 1986). Psyllid resistance has been found in other *Leucaena species* (*L. pallida* and *L. diversifolia*) and plantbreeding work has led to the development of psyllid tolerant genotypes (Bray and Woodroff 1988; Shelton, 2005). The original problem of mimosine poisoning in ruminants was overcome in 1986 by transferring rumen bacteria able to degrade DHP (3-hydroxy-4(1H)-pyridone, a poisonous breakdown product of mimosine) from Hawaii to Australia (Jones and Megarrity 1986) and this solution since spread to other parts of the tropics. *Leucaena leucocephala* has the longest record of persistence of tropical legumes with a half-life of 23 years measured in a long-term experiment in Queensland started in 1959 (Jones and Bunch 1995).

Without effective and persistent legumes, the amount of soil N and minerals available limits forage production to 8-10 t DM $ha^{-1}$ $yr^{-1}$, with a CP content of less than 7 percent. With an effective legume DM yields and CP levels can be doubled ('t Mannetje 1997). Tropical pasture legumes came into general use only after 1960.

### 6.5.1 Animal production from legume-based improved pastures

Livestock require feed throughout the year; grassland and most forage crops are not harvested at maturity like field crops as they have to be managed to supply quality herbage through as long a season as is possible. Except in humid and sub-humid climates with equitable temperatures, green herbage is not available all the year round. In temperate climates growth ceases in winter and there may be snow cover. In warmer climates growth is limited by dry seasons.

Animal production depends on the intake of digestible nutrients. There are considerable differences between species and cultivars, but the content of digestible nutrients depends on forage quality, which is determined by the state of physiological maturity at which it is grazed or harvested. Legumes maintain their quality over time much better than grasses do and have a higher intake than grasses. Tropical grasses, which are mainly tall and coarse, fast growing with a $C_4$ carbon fixation pathway, mature and lignify very rapidly; their feeding value after flowering is very low. With $C_3$ grasses of temperate regions, this is less of a problem.

### 6.5.2 Meat production in Australia

The contribution of legumes to animal production from tropical pastures has been extensively documented in Australia and to a lesser extent in Latin America, but there is a dearth of published records from Southeast Asia and particularly from Africa. The highest recorded liveweight gain of cattle with tropical legumes is 2 000 kg ha-1 yr-1 on a pure stand of irrigated *L. leucocephala* in the Ord region of Western Australia (Pratchett and Petty 1993). On herbaceous legume-grass pastures, the highest liveweight gain recorded was 937 kg $ha^{-1}$ $yr^{-1}$ on a pasture of *B. brizantha - Arachis pintoi* on fertile soil, grazed at 6 animals per ha, and 534 kg $ha^{-1}$ $year^{-1}$ at 3 animals per hectare in the humid Atlantic Zone of Costa Rica (Hernandez *et al*. 1995). In North East Queensland with comparable annual rainfall, but a distinct dry season, grass-legume pastures grazed at three animals per ha produced 550 kg LWG $ha^{-1}$ $yr^{-1}$ (Teitzel *et al*. 1991).

In areas with poorer soils and drier climates, large increases in animal production can be obtained by sowing *Stylosanthes* spp. into native pasture, or by replacing the existing pasture with grass-legume mixtures. Shaw and 't Mannetje (1970) reported a four-fold increase in liveweight gains on *Heteropogon contortus* pastures in central coastal Queensland when oversown with *S. humilis* and fertilized with superphosphate. Oversowing *S. hamata* cv. Verano in *Heteropogon* pastures in north Queensland, and fertilizing with superphosphate, allowed carrying capacity to increase ten-fold and the fattening period of cattle to be halved (Edye and Gillard 1985). But heavy grazing on *Stylosanthes*-oversown native pastures in northern Australia has resulted in the demise of perennial grasses such as *Heteropogon contortus* and weed invasion (Miller and Stockwell 1991).

The benefits of legume-based pastures have been demonstrated in South America. CIAT (1989) measured 660 and 803 kg LWG $ha^{-1}$ $yr^{-1}$ on pastures of *Andropogon gayanus-Centrosema* macrocarpum and *Brachiaria dictyoneura-Desmodium ovalifolium*, respectively, over a period of 5 years.

### 6.5.3 Milk production in Australia

Stobbs (1972) and Stobbs and Thompson (1975) reviewed experimental results from around the world and concluded that milk production on tropical grasses did not exceed 10 - 12 kg $day^{-1}$. Hamilton *et al*. (1970) reported a milk yield per cow of about 12 kg $day^{-1}$ on *Lablab purpureus* compared to 9 kg $day^{-1}$ on *C. gayana* and *Setaria anceps*.

*L. leucocephala* has a positive effect on milk (and meat) production when fed as a supplement to cows grazing N fertilized grass. Jones (1994) reviewed results from Latin America and Queensland, concluding that the average increase in milk production attributable to *L. leucocephala* was 14 percent (range 2 - 33 percent).

In Latin America, Lascano and Avila (1991;1993) reported milk production from grass-legume mixtures 13 - 20 percent higher than from grass alone. Animals with a higher genetic potential for milk production showed 18 percent higher milk production as a result of legume inclusion in the pasture, compared to 10 percent by crossbred cows of lower potential.

## 6.6 Economic aspects

Some of the major opportunities for the increased use of grassland and forage species to improve livelihoods and reduce poverty in developing countries can be best understood if we focus on their multifunctional nature (Hervieu 2002). Grasslands have a production and livelihoods potential in semi-arid areas as a genetic resource for food production, for medicinal plants, crops, energy production and resource extracting industries. Mountain (grassland) areas have a potential in terms of the development of niche products (diversified farm products) and for many natural grassland areas there is a potential to add value to livestock production in terms of "natural" products, organic meat/milk/wool and from the harvesting of wildlife meat and products with the increasing public interest in the methods employed in organic food production (Younie and Baars 2004).

Probably the most obvious indicator of future opportunities is reflected in the likely changing global demand for animal products. Wright (2005) suggests that while per capita consumption in developed countries is likely to be relatively static over the next 20 years, per capita consumption of meat and milk is forecast to increase considerably in developing countries. The International Food Policy Research Institute has developed a global food IMPACT model (Delgado *et al*. 1999) and used it to predict the growth in demand for a range of foodstuffs in different regions of the world. Much of the increased demand will be for white meat in intensive landless systems. Pig meat and poultry production systems are the most intensive and fastest growing sources of meat (Upton 2004). In the last decade, bovine and ovine meat production increased by about 40 percent, pig meat production by nearly 60 percent, while poultry meat production doubled. Pig and poultry meat each now account for about a third of meat produced worldwide. There will also be a considerable increase in the growth in demand for milk and beef (Table 6). The demand for beef will remain relatively constant up until 2020 in the developed world; there is predicted to be a doubling of beef and a 2.5-fold increase in milk demand between 1993 and 2020. Much of this increased demand is predicted to take place in China and Southeast Asia, where levels of economic growth are high. The IMPACT model (Delgado *et al*. 1999) predicts that in China, for example, meat consumption will reach 63 kg per capita, approaching the current consumption in developed countries.

TABLE 6

**Projected trends in production of selected livestock products (after Wright 2005)**

| Region/Product | Projected annual growth in production (1993–2020) | Total production (million tonne) | |
|---|---|---|---|
| | | 1993 | 2020 |
| Developed world | | | |
| Beef | 0.6 | 35 | 38 |
| Milk | 0.4 | 348 | 371 |
| Developing world | | | |
| Beef | 2.6 | 22 | 44 |
| Milk | 3.2 | 164 | 401 |

While there are these and other major opportunities for increased use of grassland and forage to improve livelihoods and reduce poverty, particularly in developing countries, there are many constraints to development as well as the need for successful models and projects that can be followed. Dixon *et al*. (2001) emphasized that small farmers produce much of the developing world's food yet will generally be much poorer than the rest of the population in these countries for the foreseeable future. Dealing with poverty and hunger in much of the world means confronting the problems that small farmers and their families face in the sustainable intensification and diversification of their agricultural systems.

On a micro-economic scale, farmers in whatever region will need to undertake economic analysis of their production systems, with particular respect to grass-N fertilizer versus grass-legume forage. Forage and feed account for a major proportion of the variable costs involved and, within these, N fertilizer figures prominently in intensively managed grassland. A competitive total feed cost per unit of commodity produced in relation to the price received is all-important, and this is achieved by using all resources to best effect. In the recent past in the United Kingdom, grass-legume systems have compared favourably in economic terms with grass-N fertilizer systems when the outputs of the two were similar and also with grass receiving about 200 kg N $ha^{-1}$ annually, but not with higher rates (300–400 kg N $ha^{-1}$) due to a lower stock carrying capacity (Doyle and Bevan 1996). Most economic models ignore the generally higher risk and higher standard of management required when relying on forage legumes rather than N fertilizer.

With the current low world prices for copra and coconut oil, monocropping of coconuts is no longer an economic proposition. Similarly, world palm oil prices have been declining recently. Unless the return to farm labour from monocropping can be sustained or increased, integrated livestock and plantation crop production will remain a competitive strategy to be adopted for high productivity of crops and maximization of land use. Crop and animal integration in plantation management should become common and widely practised in Southeast Asia.

A recent FAO study (Alexandratos *et al*. 2006) World agriculture: towards 2030/2050 gives an up-todate review of trends in livestock production. An overall increase in demand is foreseen and poultry and their products may have a particularly high potential. India is an area of rising incomes and vast demand but the population does not eat beef for cultural reasons, nor is pork favoured. The review indicates a decrease in cereal and concentrate based fattening of ruminants, possibly associated with higher costs and rising energy prices. With high oil prices and interest in biofuels, prices of cereals and livestock feed will rise, increasing the opportunities for grassland and forage based livestock production.

Although there is no published value for alfalfa hay, the estimated value in 1998 in USA was $8.1 billion according to USDA Agriculture statistics. There were 9.4 million ha of alfalfa cut for hay. Alfalfa meal and cubes were exported with a value of $49.4 million to the U.S. economy. Alfalfa is sometimes grown in mixtures with forage grasses and other legumes and the area of all hay harvested including alfalfa per year is 24.3 million ha with an estimated value of $13.4 billion. When the value of alfalfa as a mixture with other forages is considered the area and value of hay is approximately equal to wheat and soybeans (http://www.usda.gov/nass/pubs/agr98/acro98.htm).

Rapidly growing demand for biofuels production will have a major impact on the grain and livestock markets, and hence on the prospects of forage production.

## 7.ENVIRONMENTAL CONCERNS

While working towards higher food production, the need to conserve natural resources, particularly natural biodiversity, the land and its vegetation must be kept in mind. Increasing food production in developing countries has been achieved more by bringing new land into production than by increasing production per unit area or per animal, but there is now little or no new land which can be put under crop sustainably. Grasslands in Africa have been converted to crop lands and rain forests in Latin America and Asia are being cleared for crop or animal production. Grassland research and development should aim at sustainable intensification of production on already cleared land, with higher yields per animal and per hectare, without polluting the environment or degrading the land.

Research and cultivar development programmes related to genetic resources of grasslands concentrate on aspects such as pasture production, pest resistance and nutritive value. Breeding of forage species is limited to nutritive quality, disease and pest problems. There are few or no plant breeding programmes to identify cultivars that use N more efficiently, or are better adapted to difficult environments and stresses. Some of these problems can be solved by selection of appropriate species and by management. The grass breeding work of IGER in the UK has produced new cultivars of perennial ryegrass (*L. perenne*) with higher WSC which leads to higher N efficiency (Humphreys and Theodourou 2001).

The aim of sustainable forage crops and pasture production is to achieve efficient and economic production while managing and protecting the environment. There are several environmental issues related to forage crops and grasslands that are increasingly addressed at national and regional level.

### 7.1 Global warming and pasture genetic resources ('t Mannetje 2007 a)

Climate change expresses itself in the natural grassland-forest equilibrium. Long periods of low rainfall lead to fewer trees and more grassland. In relation to global warming, the existence of $C_3$- and $C_4$- type grasses is very important, because $C_4$ grasses grow at higher temperatures (optimum 30-35 $^oC$), absorb CO2 more efficiently and have greater water-use efficiency than $C_3$-grasses.

Rising temperatures would give a competitive advantage to $C_4$ - species. $C_4$- grasses have a greater DM production capacity than $C_3$ - grasses, but the feeding value of $C_4$ - grasses is lower than $C_3$ - grasses, because higher temperatures lead to lower digestibility values and $C_4$ - grasses have a greater proportion of less digestible tissues (Hill *et al*., 1989). Transitional regions between warm- and coolclimate grasslands contain both $C_3$- and $C_4$- grasses, e.g. in northern New Zealand (Campbell and Mitchell, 1996), Australia (Johnston, 1996), South Africa (Franz-Odendaal *et al*. 2002) and Greece (Papanastasis 1998). With increasing temperatures and drier weather, a shift towards more $C_4$ species is likely. This will have negative effects on feed quality from these grasslands. For example, *Chrysopogon gryllus* and *Dichanthium ischaemum*, which are widely distributed in more humid parts of central and southern Europe, are low quality stemmy invasive grasses. *Cynodon dactylon* is found in overgrazed grasslands and *Hyparrhenia hirta* in the warmer parts of the northern Mediterranean (Papanastasis, 1998). The following $C_4$ grasses, many of which are weeds, occur in the European Mediterranean region: *Andropogon ischaemum*, *A. hirtum*, *Chrysopogon gryllus*, *Cynodon dactylon*, *Dichanthium ischaemum*, *Digitaria* spp., *Echinochloa crus-galli, Eleusine coracana*, *Eragrostis pilosa, E. megastacya, E. poacoides, Hyparrhenia hirta, Imperata arundinacea, Panicum sanguinale, P. lineare, P. debile, Paspalum dilatatum, P. vaginatum, P. distichum, Setaria verticillata, S. italica, S. glauca, S. viridis, Sorghum halepense, Sporobolus pungens* and *Stipa* spp. These species may increase in abundance in the European Mediterranean region with increased temperatures and drier weather. If and as climate change progresses, crops, forages and pastures included, may come under stress in the zones where they have been grown traditionally. There are many species already in use with a wide range of climatic adaptation and one forage can be substituted for another to suit the climate. The first priority in breeding would be the screening and development of the vast amount of material already available to develop a robust range of cultivars of each species. It would be prudent to increase collection and screening of more material of forages already in use so that, as change comes, the material will be available to develop cultivars adapted to the new conditions.

An excellent recent review on climate change and grasslands was published by Morgan (2005).

### 7.2 Climate change and maintaining forage production

A wide range of genetic resources are necessary to maintain forage production in the face of climate change. In some cases changing cultivars may suffice; in more extreme cases other species may have to be used. Fortunately there is a high degree of species substitution possible in fodders and species for sown pasture but selection and breeding may be required since many hardier species have lower feeding values than commonly used pasture plants. If the trend to lower energy input systems continues cultivars tolerant of lower fertility may also be desirable. North America, with a greater climatic variation, grows a far greater range of forages than does Western Europe and the temperate zones of Australasia and Latin America; these and their adaptations are described by Barnes *et al*. (2007).

Extensive natural grasslands generally contain a very wide range of plants. Their adaptation to changing climate will have to be through natural shifts in their specific composition, assisted where necessary by careful grazing management.

## 7.3 Carbon sequestration ('t Mannetje 2007b)

Most of the carbon stored by pastures and grasslands is in soil organic matter. Grasslands release CO2 to the atmosphere as a result of respiration, burning and the fermentation of feed in the rumen. The amount of C accumulation in the soil depends on the Net Primary Production (NPP) (DM growth minus respiration) of the vegetation. $C_4$ grasses have a greater NPP than $C_3$ grasses and legumes. Therefore, net C sequestration by grassland will be higher in tropical than in temperate zones. Long and Jones (1992) estimated that tropical grasslands alone store 26 percent of the total terrestrial C, tropical forest 19 percent.

The use of improved grasses and legumes improves production and increases the C sequestration potential compared to native grassland. In the Llanos of Colombia, Fisher *et al*. (1994) measured C storage of 237 tonnes $ha^{-1}$ under a 6-year-old *Andropogon gayanus* - *Stylosanthes capitata* pasture, with about half of it in the 40-100 cm soil layer, compared with 186 tonnes $ha^{-1}$ under unimproved savanna. C sequestration depends on dry matter production and it has not been a goal in itself in grassland husbandry until today.

A major aspect that will have increasing significance is whether farmers and pastoralists should be paid for environmental services (Miranda *et al*. 2003; Lipper and Cavatassi 2003).

## 7.4 Methane emissions ('t Mannetje 2002)

As a contributor to greenhouse gas emissions, CH4 is second only to CO2. CH4 is four to six times more thermogenic than $CO_2$. $CH_4$ emissions to the atmosphere arise largely from anaerobic ecosystems such as natural wetlands (20 percent), paddy fields (20 percent), fermentative digestion systems of ruminants and other herbivorous mammals that possess a hindgut fermentation system (15- 22 percent), oceans, lakes, biomass burning, natural gas, coal mining and rubbish tips. In rangelands $CH_4$ is produced by wild and domestic grazing animals and by a proportion of the faecal materials decomposing anaerobically. Rumen micro-organisms ferment forages to volatile fatty acids with $CH_4$ and $CO_2$ as by-products. A proportionally larger part of the metabolisable energy intake of ruminants is transformed into $CH_4$ from poor quality feed (15 - 18 percent), such as that produced by grasslands and many crop residues in the tropics, compared to high quality feed (7 percent) such as Lolium perenne (Goossensen and Meeuwissen 1990; Leng 1993). Therefore, it is not only important to improve grasslands in the tropics for higher feed production, but as a side effect there will be less $CH_4$ emitted per unit of feed intake. According to Howden *et al*. (1994) globally, ruminant livestock produce about 80 million tonnes of $CH_4$ annually, accounting for about 22 percent of global $CH_4$ emissions from human-related activities. An adult cow may be a very small source by itself, emitting only 80-120 kg $yr^{-1}$ of $CH_4$, but with about 1.2 billion large ruminants in the world, ruminants are one of the largest $CH_4$ sources.

## 7.5 Nitrogen emissions

All grazed grassland systems contribute to N emissions to the environment:

- $NH_3$ volatilization from animal excreta, which harms nature
- $N_2O$ from denitrification, which contributes to global warming
- $NO_3$ leaching from fertilizers, urine and dung spots and slurry, which pollutes surface and ground water.

Since the size of N flows in extensively grazed rangelands will be small, extensive grasslands can be taken as not contributing significantly to N emission but intensively managed temperate pastures contribute heavily to environmentally harmful emissions of N (and P) (Van der Meer 2001).

## 7.6 Environmental impact of pasture improvement

Improvements in grassland management which lead to better soil cover, reduction of erosion and maintenance of biodiversity are beneficial to the environment. Clearing of forest for installation of sown pasture, of doubtful sustainability, is very damaging and has been undertaken on a vast scale in recent years, notably in Brazil. Many of the activities associated with improvement of natural grasslands, tree-felling, bush-clearing and overseeding, with or without fire are invasive and, especially on marginal land, require assessment of their overall, environmental effect and sustainability.

### 7.6.1 Problems with forage plant introductions

Demand for new, more productive, better quality forages is enormous. But some caution is relevant when considering the widespread introduction of potentially productive new forage species. Firstly, there is the danger of genetic erosion of existing adapted landraces. Secondly, some forages prove invasive in new habitats. Thirdly, there is an example where transfer of successful Australian pasture technology based on annual subterranean clover (*T. subterraneum*) and application of phosphorus (P) did not have as significant an effect in other Mediterranean-climate-type regions (Seligman, 1996), because of socio-economic conditions, often related to land tenure patterns or to subsidised feed. Development of local ecotypes, even if regarded as lesser species, may be more appropriate and rewarding than attempting to adapt existing major species to fit all conceivable agro-ecological environments.

### 7.6.2 Invasive species

The ability to spread and colonise in a grazing situation was a desirable characteristic of pasture plants – now such plants may be regarded as invasive aliens. For rotations, plants must be easy to extirpate at the end of the pasture phase.

Among the worst weeds in agriculture are grasses, *Elytrigia repens, Alopecurus myusuroides, Arrhenatherum elatius* var. *bulbosum*; *Avena fatua* and A. *ludoviciana* are serious weeds in temperate crops. Some grass weed species are also desired plants in grassland and fodder crop situations, e.g. *Cenchrus ciliaris*, *Chloris gayana*, *Cynodon dactylon*, *Panicum maximum*, *Paspalum dilatatum*, *Pennisetum clandestinum* and *Sorghum halepense* (Low 1997). *Imperata cylindrica* is both a serious weed of crops and an invader of improved tropical pastures. Pasture legumes are less troublesome but the introduced kudzu, *Pueraria montana*, has become very troublesome in parts of the USA and is now listed as a Federal Noxious Weed.

Often, exotic species are more vigorous and produce higher yields than indigenous ones, but there is a danger that they displace indigenous species. In India, fast growing, multipurpose exotic tree species were introduced alongside the relatively slow growing *Acacia nilotica* to enhance biomass production. However, competition reduced growth of the indigenous species. Careful planning and thoughtful species selection is recommended before implementation of exotic large-scale afforestation programmes (Neelam-Bhatnagar *et al*.1993). *Prosopis juliflora* is a serious pest of rangeland in the southern USA but has been widely introduced in revegetation programmes in the drier parts of Africa and Asia; it is now seriously invasive in many countries.

In South Africa, invasive exotic plants, such as *Acacia longifolia* and *A. mearnsi*i, were detrimental to native, ground-living, invertebrate fauna. There was no significant effect on species richness and diversity, but there was a different assemblage of species associated with exotic compared with indigenous vegetation. Management should be sensitive to the needs of the ecosystem to ensure conservation of desirable species when native vegetation is supplanted by exotics (Samways *et al*. 1996).

Over the last three decades, there has been movement of plant material around the world on an unprecedented scale, with few restrictions covering movement. Hughes (1994) advocated a more cautious approach to species introduction and a more thorough assessment of the advantages and limitations of native and exotic species to lessen the risks of introduction of a weed. Many native plants are incompletely studied; some are only now undergoing preliminary domestication or are still harvested by the traditional gathering activities associated with wild species. A case in point is *Faidherbia albida*, which is now the focus of international collaborative efforts to extend its versatility of utilization (Nouaille 1992). There is large variability in performance of individual trees, little plant improvement has occurred, and little is known of the s-ilviculture of the species (Cromwell *et al*. 1996).

A species may be valuable in one forage situation, but a weed in another. *Heteropogon contortus*, the dominating grass in unimproved savanna in northern Australia is a valued species for cattle, but noxious for sheep and a weed in sown grass-legume pastures. Species of *Brachiaria* have been very widely used for grassland establishment, particularly in Latin America, but can cause photosensitivity in ruminants, caused by the mycotoxin sporidesmin, produced by the fungus *Pithomyces chartarum* on the grass (CIAT 1981).

Weeds in grasslands cause great economic losses, not only from reduced yields and nutritive value, but also directly. In Queensland, Australia, the annual wool clip was estimated to be reduced in value by $A 4 000 000 as a result of contamination by *Xanthium pungens* and annually about 5 000 tonnes of butter was tainted by the weed *Coronopus didymus*. (Bailey 1988). Animal deaths have been caused by the legume genus Astralagus in the United States and by *Acacia georginae* and *Gastrolobium grandiflorum* in Queensland.

Very large areas in the tropics are covered by *Imperata cylindrica*, often in nearly pure stands. This unpalatable, strongly rhizomatous grass is hard to eradicate, burns easily and makes the reestablishment of forest cover difficult. It usually establishes itself when forest has been cleared, often for crop production. It occurs throughout the tropics; the total area has not been established but in Asia alone Garrity *et al*. (1997) estimate that the area of *Imperata* is 35 M hectares. It is not eaten by cattle except shortly after burning.

## 7.7 Diseases and pests in forages

In the past two decades there have been important outbreaks of diseases and pests, some of which have caused serious economic losses. Among the important forage legumes affected by diseases and pests:

*Stylosanthes* spp. are attacked by anthracnose, a fungal disease caused by *Colletotrichum gloeosporioides*; leucaena attacked by leucaena psyllids (*Heteropsylla cubana*) siratro attacked by Rhizoctonia fungus and lupins succumbing to a root rot caused by *Sclerotia rolfsii*. Among the forage grasses affected by diseases and pests are *Chloris* that is attacked by *Fusarium graminearum*; Cynodon attacked by *Helminthosporium cynodontis*; *Panicum* attacked by *Cerebella andropogonis*; some *Brachiaria* spp. are attacked by spittle bug (*Homoptera*: Cercopidae), which reduces stocking rate, milk and meat productivity; *Paspalum* spp. are attacked by *Claviceps purpurea*, with the danger of animal poisoning and Kikuyu grass is attacked by the root knot nematode, *Meloidogyne kikuyuyensis*.

# 8. AUXILIARY USE OF FORAGES AND GRASSLANDS SPECIES

Grassland plants have many uses in addition to their role as livestock feed. They are often the major source of thatch for traditional houses. The strong flower-stems of some grasses (*Arundo*, *Phragmites*, *Saccharum* spp.) are used in light building and in furniture. Some are harvested for fibre and paperstock, notably Stipa tenacissima ('alfa) and *Lygeum spartium* (esparto) from the North African steppes.

The seed of several wild grasses are harvested in the Sahelian region of Africa for human food, sometimes routinely, sometimes as famine food (Batello *et al*. 2004). These grasses include *Digitaria exilis*, *Dactyloctenium aegyptium*, *Echinochloa pyramidalis*, *Cenchrus* spp., *Oryza* spp., and *Eleusine indica*.

Temperate pasture legumes, notably white clover and lucerne, are important sources of honey.

## 8.1 Fertility maintenance and rotations

Pasture and fodder crops have, traditionally, been very important in maintaining soil fertility in mixed farming systems. Their effects are several. A pasture phase in a rotation builds up soil organic matter and, if a well-nodulated legume is used also contributes nitrogen to the overall farm system; the pasture provides a break in the cycle of crop pests and diseases. Most arable weeds cannot develop during a period of temporary grassland and their seed bank decreases in the soil.

Rotations have waned in importance since the mid twentieth century with the advent of cheap mineral fertilisers but their advantages are increasingly being recognised with a return to more ecologically friendly production methods. Fodder crops are important for fertility maintenance in some smallholder systems: *Trifolium alexandrinum* is grown as a winter fodder on millions of hectares in the irrigated lands of Egypt and the Indo-Gangetic plain; *Trifolium resupinatum* is part of many Afghan systems; *Astragalus sinicus* is widely grown as a winter crop on rice land in southern China.

Yields of sown pasture are not usually stable; they reach a peak, often in the second or third year, and tail off thereafter; quality also falls with time. In many systems it is more practical and productive to grow pasture as three or four year phases in rotation than to try to maintain old stands. The accumulated fertility benefits the crops in the rotation and livestock have a regular supply of high quality forage.

Rotational pastures are regaining popularity and are especially necessary in organic production systems. Grass and legume cultivars suitable for mixtures and adapted to modest fertility conditions will be needed to support this change in practice. Pasture is now being introduced into Conservation Agriculture systems; this is discussed at 8.2.1

## 8.2 Erosion control

Perennial grasses are excellent protectors of the soil surface and prevent erosion with turf-forming species having the greatest effect. Grasses are used to stabilise earthworks designed to reduce soil erosion: terraces, filter strips, watercourses and protection of riparian areas. Many pasture species are used according to climate and situation; soil conservation grasses must not, of course, be invasive or liable to compete with adjacent crops. High palatability is not desirable unless the grasses are to be cut as livestock feed. Some unpalatable grasses are so used and *Vetiveria zizanoides* has been greatly touted for use in farm lands.

*Ammophila* spp. (Marram grasses) are adapted to the harsh conditions of sand dunes in temperate climates and very drought tolerant. Marram grass is an excellent sand binder for shifting sands due to its fast growing rhizomes. *Ammophila arenaria*, European marram grass protects the coasts of Europe including Iceland and northwest Africa.

### 8.2.1 Conservation agriculture

Conservation Agriculture, which combines zero tillage with the maintenance of a surface mulch to protect the soil surface and increase biological activity in the topsoil is increasingly becoming recognised as an effective system of crop production which protects the soil from erosion while reducing the overall use of agrochemicals. The distinguishing and most important element of Conservation Agriculture is that crop residues remain on the surface, including those of "cover crops" (green manures). This technology is developing rapidly and pastures are now being used as part of the rotation; adapted cultivars of grasses and legumes suited to conservation technology are needed.

## 8.3 Production of aromatic substances, and traditional medicines

Essential oils from grasses, for which there is a large worldwide demand, are extracted from fresh or partly dried leaves by steam distillation. These grasses are specialised crops grown for oil extraction, not collected from grazed stands. Their ancestors and close relatives are, however, present in grasslands whence genetic resources must be sought.

Grasses for essential oils include: *Vetiveria zizanoides*; several species of *Cymbopogon - Cymbopogon citratus* (Lemon grass), *Cymbopogon martini* (palmarosa grass), *Cymbopogon winterianus* (syn. Cymbopogon nardus) (citronella grass) and *Hierochloe odorata* (sweet grass, vanilla grass, bison grass, zebrovka). These have various uses as scents, flavourings and in medicine.

## 8.4 Bio-energy production

The development of alternative sources to fossil fuels for energy from fast-growing grasses, legumes and trees, in particular those that can thrive in less fertile and more drought-prone regions and are less competitive with food and feed production, is considered urgent for two reasons: 1) the reserves of fossil fuels are finite and reaching low levels 2) fossil fuel burning leads to huge releases of $CO_2$ to the atmosphere, whilst vegetative fuel is $CO_2$ neutral.

Biomass energy was about 6.7 percent of the world's total energy consumption in 1990. For 2000, the data compiled by the International Energy Agency (IEA) from a survey of 133 countries, indicate that biomass' share of total energy consumption, 430 EJ (408 quad), for these countries is about 10.5 percent.

The genus *Miscanthus* is receiving attention as a potential source of biomass for biofuels. Giant Miscanthus (*Miscanthus* x *giganteus*) is a hybrid that can grow four metres high. The biomass from one hectare of miscanthus can produce about 17 000 litres of ethanol. Alternatively, after harvest miscanthus can be burned to produce heat and power turbines or can be mixed with coal in equal amounts for use in coal-burning power plants without modification. The main grass species used in trial projects in Europe is *Miscanthus sinensis*, which is native to Asia and the Pacific islands. It can be gasified and turned into a liquid fuel or used as the feedstock for cellulous ethanol, as well as a chemical feedstock for future biorefineries. In the United Kingdom DEFRA has allocated £29 million to the Energy Crops Scheme to promote planting of miscanthus. Farmers receive £920 per hectare in addition to direct farm payments. They must plant a minimum of three hectares and need to have an agreement to supply the crop to a power station and the crop must be grown within a reasonable distance of it. The land may be part of the set-aside area. More research is needed in this area.

Switchgrass (*Panicum virgatum*), a perennial native to the North American prairies, could provide more than 450 billion litres of biofuels per year, while allowing animal feed, and export demands for other crops to be met. Switchgrass can grow on lands incapable of supporting traditional food crops, with 12 percent of the N runoff and 10 percent of the soil erosion of conventional crops. Its deep root system adds organic matter to the soil, rather than depleting it. Breeding programmes aim at least to double yields (currently about 10 tons per ha) and raise ethanol output to about 450 litres per ton in the medium term.

The quality of timber or grassy biomass does not have a direct impact on its value as an energy source. However, the use of vegetable oils and biomass for fuel requires huge areas of agricultural land and can only fulfil a small proportion of the energy need. The use of food crops such as maize for biofuels, has led to increased prices for maize food products, such as maize tortillas, which is a staple food in Mexico, by 50 percent. This has caused unrest in the country and hardship to poor people.

## 8.5 Grasses for grey water treatment

Grey water, domestic wastewater (all household water except sewage) constitutes 50 – 80 percent of the water used in households. Black and grey water in industrialised countries are commonly removed from urban areas to water treatment plants. Wetland plant species are well-suited for use in filter systems. The actual species to be used depends on climatic conditions. Plants must be tolerant of alkaline conditions, because grey water usually contains laundry detergents which contain Na, K, and Ca. Emergent Aquatic plants such as Common Reed (*Phragmites*), Reedmace (*Typha*) and Bulrush (*Scirpus*), which tolerate saturated conditions, provide structure to induce enhanced flocculation and sedimentation, are windbreaks and insulate during winter months.

## 8.6 Amenity plantings, sports grounds and lawns

Many grassland species are used in amenity plantings, sports grounds, road verges, lawns and the like; the areas involved are considerable but not inventoried. Some are species used for sown pasture but usually of different, specialised turf cultivars. Breeding and seed production of amenity and turf plants is a considerable industry, separate from that of grasslands.

## 8.7 Rehabilitation of degraded lands

There is an increasing need to rehabilitate land which has been devastated by industries such as mining and oil extraction and other industrial uses or extensive grazing lands which are important catchments. Many of the species and techniques used are grassland ones although trees and shrubs are also involved.

Degraded grassland is a symptom of weaknesses in the pastoral production system which must be dealt with before further action can be taken. Rehabilitation should be through management and this will necessitate involvement of the grazing community or ranch managers. Overseeding degraded grassland is rarely attractive economically and reliance has to be put on the recovery of the natural vegetation. In areas of exceptional environmental importance such as major catchments and foci of erosion some agronomic interventions may be justified.

Old mining sites and oilfields have undergone much disturbance and their soils are usually impoverished; they may be in harsh environments. Degraded grassland areas are also often on the poorer sites. In most cases the species or cultivars used are for sown grassland or grassland improvement. Suitable genetic material is required when dealing with such sites if a lasting vegetative cover is to be attained. In some cases the material used may be site-specific. Production and supply of seed and planting material may have to be organised to suit sites or groups of sites.

# 9. CONCLUSIONS

## 9.1 Overview

Small farmers and pastoralists produce much of the developing world's food and are generally much poorer than the rest of the population in these countries; for the foreseeable future, therefore, dealing with poverty and hunger in much of the world means confronting the problems that small farmers and their families face in the sustainable intensification and diversification of their agricultural systems. To meet the demand for livestock products there will be increased reliance on forage based production systems. In many smallholder mixed farming systems fodder crops are increasingly used to supplement crop residues as the basis of ruminant rations.

Grasslands are multifunctional and have a production and livelihoods potential as a genetic resource for food production, for medicinal plants, crops, energy production, resource extracting industries, carbon sequestration and the use of many grassland areas for watershed protection, polluted-land rehabilitation and bio-energy production.

There is an overall dramatic need to support the conservation of forage crops genetic resources that are important for food and feed production. Grasslands are the great genetic reservoir of forage species for sustaining and improving the productivity of sown pastures used for intensive livestock production in all environments, and support pastoralist (herder) and ranching production systems that form the livelihood of several hundred million people, largely but not solely in developing countries.

Virtually all countries will benefit from access to additional diversity, including from the species' centres of origin. This perennial interdependence will require exchange of an increasing range of plant genetic resources, particularly of forage, pasture and grassland species.

Close collaboration and synergies for action should be planned with the activities related to animal genetic resource conservation because these are inextricably linked and dependent on grasslands and forage crops, for their feeding base. National and international activities to promote *in situ* (and *ex situ*) conservation, characterisation, and availability of forage genetic resources should become a high priority in the agenda of member countries.

Hence there is a need to develop specific instruments and activities, guided by the Commission on Genetic Resources for Food and Agriculture and its Intergovernmental Technical Working Group on Plant Genetic Resources. They would constitute components or elements under the existing framework for the responsible exploitation, management and conservation of the genetic resources of forage crops, pasture and grasslands: the Global Plan of Action for Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture, which was reinforced by the International Treaty[1]. Such elements could be regulatory instruments, contractual arrangements, bilateral and multilateral funding modalities, voluntary agreements, standards or codes of conduct, and cooperative arrangements and alliances for, for example, the exchange, structuring and dissemination of information, findings and insights. The instruments and activities should also acknowledge, according to criteria of food security and interdependence, the contribution that pastoralists and farmers of all ecosystems of the world, and in particular those in the centres of origin and diversity of forage and grassland species, provide through their daily management and use of the genetic resource.

## 9.2 Priority activity areas

### 9.2.1 *In situ* conservation and development

1. Surveying and inventorying plant genetic resources for food and agriculture. Genetic erosion of pasture and grassland species is continuing, caused by mismanagement of grasslands; the loss of pasture and grassland diversity cannot be estimated since there is no inventory. The floristic composition and biodiversity of natural grassland depends on its management. Much of the remaining natural grasslands are under stress from overgrazing and mismanagement, whether they be commercially or traditionally managed and are degrading rapidly; unless there is a massive international determination to conserve grassland areas, there may be limited value in *in situ* conservation in large parts of the world in twenty years from now.

[1] The 1996 Leipzig Declaration and Global Plan of Action for Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture, and the 2001 International Treaty on Plant Genetic Resources for Food and Agriculture, which succeeded the 1983 International Undertaking on Plant Genetic Resources. An existing instrument that fits under the framework is the 1993 International Code of Conduct for Germplasm Collection and Transfer.

2. Much smallholder fodder is in local, farmer maintained cultivars. Many are in need of study and improvement to increase the efficiency of production *in situ*ations where land is scarce. Availability and distribution of seed must form part of any such programme.

3. Promoting *in situ* conservation of wild crop relatives and wild plants for food production. *In situ* conservation is common for wildlife and forest genetic resources; there is potential to use *in situ* approaches for genetic resources of forage, grassland and pasture species. The floristic composition of grasslands depend on their management and the presence of grazing animals; *in situ* conservation must take this into account and the grazing community must be part of the process. This means that pastoralists (or ranchers) must participate in the planning and management from the outset; due attention will thus need to be paid to both conservation and productivity questions, and to associated economic and social constraints.

International cooperation is necessary for efficient monitoring of forage crops, pasture and grassland genetic resources and their use, management and maintenance by farmers and pastoralists, but Governments need to be made aware of the need to engage in *in situ* and *ex situ* conservation programmes. Successful cooperation would depend on government investments and international cooperation in the conservation of genetic resources, otherwise effort spent in collecting and multiplication would be futile. Tropical pasture cultivars have been obtained by recent selection within collections of wild species or by breeding. Seed of these cultivars and their close relatives need to be conserved in gene banks for future use. There is need to develop legislations concerning local germplasm protection in different ecosystems in harmony with legislations and agreements on germplasm protection at national and international level.

### 9.2.2 *Ex situ* conservation of genetic resources

1. Sustaining *ex situ* collections. Problems of managing increasing species diversity are emerging, particularly for *ex situ* collections of wild species. The great concern about species extinction caused by deforestation, agriculture and overgrazing, will enhance the need to further develop *ex situ* collections. At the same time regeneration for a large number of old accessions is urgently required.

2. Regenerating threatened *ex situ* accessions. There are financial problems with the maintenance and further development of international tropical forage gene banks. At present only the CGIAR institutes ILRI and CIAT hold significant numbers of species in long term storage that are available for international exchange.

3. Supporting planned and targeted collecting of plant genetic resources for food and agriculture. Genetic material is often as yet patchily collected and, since it concerns new species for agriculture, breeders frequently require access to novel material; collection is complicated since it has to be done in the wild with problems of access and of choosing the right dates for seed collection. The genetic base of sown pastures is very narrow. This highlights the urgent need to widen the choice of available high-value grass and legume cultivars by exploring, evaluating and selecting from a wide range of species of several genera.

4. Expanding *ex situ* conservation. On a world scale about 100 to 150 forage species have undergone selection or at least been cultivated out of a total of 12 000 species of grasses and 18 000 species of legumes. It has been estimated that approximately 3 000 species have potential value as cultivated forages in the tropics.

It is necessary to strengthen the economic support to research, cultivar development, maintenance of genetic resources of forage crops, pastures and grassland species in order to be prepared for extreme events such as climate change and desertification. International coordination is needed to identify major goals for cultivar development of fodder crops, pasture and grassland species in relation to forage production as well as to the main auxillary uses of the genetic resources.

### 9.2.3 Utilization of plant genetic resources

1. Expanding the characterization, evaluation and number of core collections to facilitate use. The reproductive behaviour, ploidy levels and chromosome behaviour of tropical grasses, essential for deciding selection and breeding procedures have not been determined. Since pasture cultivars are still in the process of domestication, natural grasslands are a major source of genetic material for selection programmes.

2. Promoting sustainable agriculture through diversification of crop production and broader diversity in crops. Organic farming is beginning to expand world-wide. More varieties of fodder and pasture grasses and legumes are needed for biological nitrogen fixation, which is of paramount importance for maintaining soil fertility. Conservation (mulch + zero

tillage) Agriculture is expanding and requires cover-crops, green manures and mulches. In many areas large areas of pasture are being sown with a very limited genetic base. International efforts are needed to select and make available to farmers a broader choice of fodder crops and forages to increase biodiversity of the crop production systems and maintain sustainable ecosystem functions.

The gap between results from the research and farmer's adoption must be overcome. The development of a cultivar does not ensure its adoption. Seed of planting material must be produced and an infrastructure is needed for quality control and distribution.

3. Supporting seed production and distribution. Large numbers of accessions of tropical species are held in gene-banks and collections but new forages are not being released proportionally; it is absolutely necessary that in most institutions where these evaluations have taken place, continuity be given through the complete process from evaluation to release. Therefore international collaboration and assistance is needed to strengthen seed systems in particular addressing the seed security needs of smallholder farmers. Much smallholder fodder consists of local, farmer-maintained cultivars. Many are in need of study and improvement to increase the efficiency of production *in situ*ations where land is scarce. Lack of production and distribution of seed are constraints for such programmes.

12. Developing new markets for local cultivars and "diversity-rich" products. Given the importance of wild cereals, food plants and grasslands in the livelihood of poor communities and pastoralists, and the importance that many grasses and legumes hold for livestock production and stress adaptation, additional efforts should be made to address their conservation in protected areas.

### 9.2.4 Institutions and capacity building

1. Building strong national programmes. Many countries hold a significant amount of plant genetic diversity for food and agriculture in their gene banks, farmers' fields, and natural grasslands, but in the long-term, they are likely to require access to additional diversity from the crop species' centres of diversity. There is a continued need for exchange of plant genetic resources. Free international exchange of tropical forage plant resources has been reduced severely. There is a need to promote availability and sustainable use, management and breeding of forage crops, pasture and grassland species by providing a flexible framework for sharing the benefits and burdens.

2. Constructing comprehensive information systems for plant genetic resources for food and agriculture. Information sharing and environmental assessment are necessary to understand and regulate the impact of introduction of new fodder crops, forages, and grassland species into existing ecosystems and cropping systems. The possibility of species being invasive must be carefully embedded in all research, selection, and conservation programmes.

3. Developing monitoring and early warning systems for loss of plant genetic resources for food and agriculture. The loss of fodder, pasture and grassland diversity cannot be estimated since there is no inventory. Many species are from montane areas and in natural grasslands. Inventories of forage, pasture and grassland species found *in situ* and detailed assessments of genetic diversity within *ex situ* collections will be needed to provide information for work and to measure progress in the conservation of PGRFA.

Genetic erosion of forage species caused by agricultural and urban encroaching and unsustainable management is continuing. This loss has dramatic consequences at country level, but also, at global level, given the role that these species could play, besides animal feeding, for further generations. Conservation programmes should be clearly focussed on preserving the many multi-functional characteristics of the different species.

International cooperation is necessary for efficient monitoring of fodder crops, pasture and grassland Genetic Resources and their use, management and maintenance by farmers and pastoralists, but Governments need to be called to directly engage in support of *in situ* and *ex situ* conservation programmes.

4. Expanding and improving education and training. The genetic composition and structure of plant populations in reserves should be of primary research interest, for the study of co-evolutionary selection pressures in stressful environments. The development of *in situ* conservation programmes will require the joint efforts and support of farmers, countries, and international organizations. Progress in the establishment of soundly based *in situ* conservation programmes for grasslands could be difficult and time consuming, but it is certainly a priority need for centres of diversity. Efforts to increase education and training of farmers and pastoralist, extension officers of developing countries is a priority to improve *in situ* sustainable use and management of local pasture and grassland species, and to improve the use in modern and sustainable cropping systems of fodder crops and pasture species.

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# FORAGES IN APPENDIX 1 OF THE TREATY

| Genera | Species |
|---|---|
| | **LEGUME FORAGES** |
| *Astragalus* | *chinensis, cicer, arenarius* |
| *Canavalia* | *ensiformis* |
| *Hedysarum* | *coronarium* |
| *Lathyrus* | *cicera, ciliolatus, hirsutus, ochrus, odoratus, sativus* |
| *Lespedeza* | *cuneata, striata, stipulacea* |
| *Lotus* | *corniculatus, subbiflorus, uliginosus* |
| *Lupinus* | *albus, angustifolius, luteus* |
| *Medicago* | *arborea, falcata, sativa, scutellata, rigidula, truncatula* |
| *Melilotus* | *albus, officinalis* |
| *Onobrychis* | *viciifolia* |
| *Ornithopus* | *sativus* |
| *Prosopis* | *affinis, alba, chilensis, nigra, pallida* |
| *Pueraria* | *phaseoloides* |
| *Trifolium* | *alexandrinum, alpestre, ambiguum, angustifolium, arvense, agrocicerum, hybridum, incarnatum, pratense, repens, resupinatum, rueppellianum, semipilosum, subterraneum, vesiculosum* |
| | **GRASS FORAGES** |
| *Andropogon* | *gayanus* |
| *Agropyron* | *cristatum, desertorum* |
| *Agrostis* | *stolonifera, tenuis* |
| *Alopecurus* | *pratensis* |
| *Arrhenatherum* | *elatius* |
| *Dactylis* | *glomerata* |
| *Festuca* | *arundinacea, gigantea, heterophylla, ovina, pratensis, rubra* |
| *Lolium* | *hybridum, multiflorum, perenne, rigidum, temulentum* |
| *Phalaris* | *aquatica, arundinacea* |
| *Phleum* | *pratense* |
| *Poa* | *alpina, annua, pratensis* |
| *Tripsacum* | *laxum* |
| | **OTHER FORAGES** |
| *Atriplex* | *halimus, nummularia* |
| *Salsola* | *vermiculata* |
| **GRASSES** | |
| *Acroceras* | *macrum* |
| *Anthoxanthum* | *odoratum* |
| *Axonopus* | *affinis, compressus* |
| ***Bothriochloa*** | *insculpta, ischaemum, pertusa* |
| *Bouteloua* | *curtipendula* |
| *Brachiaria* | *brizantha, decumbens, humidicola, mutica, ruziziensis* |
| *Bromus* | *catharticus,inermis, mollis* |
| *Cenchrus* | *biflorus, ciliaris, setigerus* |
| *Chloris* | *gayana* |
| *Chrysopogon* | *aucheri* |
| *Coix* | *lachryma-jobi* |
| *Cynodon* | *aethiopicus, dactylon, nlemfuensis* |

| Genera | Species |
|---|---|
| *Cynosurus* | *cristatus* |
| *Dactyloctenium* | *aegyptium, bogdanii* |
| *Dichanthium* | *annulatum, aristatum, caricosum* |
| *Digitaria* | *decumbens, didactyla, pentzii, swazilandensis* |
| *Diplachne* | *fusca* |
| *Echinochloa* | *colona, frumentacea, pyrimidalis, stsgnina* |
| *Elymus* | *nutans, repens* |
| *Eragrostis* | *curvula, superba, tef* |
| *Hemarthria spp.* | |
| *Hyparrhenia* | *filipendula, rufa* |
| *Ischaemum* | *pilosum* |
| *Leersia* | *hexandra* |
| *Melinis* | *minutiflora* |
| *Panicum* | *antidotale, coloratum, maximum, miliaceum, turgidum* |
| *Paspalum* | *conjugatum, dilitatum, notatum, plicatulum* |
| *Pennisetum* | *americanum, clandestinum, polystachyon, purpureum* |
| *Setaria* | *italica, sphacelata* |
| *Sorghastrum* | *nutans* |
| **Sorghum** | *almum, halepense, x drumondii* |
| *Stenotaphrum* | *dimidiatum* |
| *Themeda* | *triandra* |
| *Tripsacum* | *latifolium, laxum* |
| *Urochloa* | *mosambicensis* |
| *Zea* | *mexicana* |
| **LEGUMES** | |
| **Acacia** | *niilotica* |
| *Aeschynomone* | *americana, indica* |
| *Arachis* | *glabrata, monticola, pintoi, villosa* |
| *Calliandra* | *calothyrsus* |
| *Calopogonium* | *mucunoides* |
| *Chamaecrista* | *rotundifolia* |
| *Centrosema* | *acutifolium,brasilianum,pascuorum, plumeri, pubescens, virginianum* |
| *Chamaecytisus* | *palmensis* |
| *Clitoria* | *ternatea* |
| *Cyamopsis* | *tetragonaloba* |
| *Desmodium* | *heterophyllum, intortum, uncinatum* |
| *Faidherbia* | *albida* |
| *Galega* | *orientalis* |
| *Gliricidia* | *sepium* |
| *Lablab* | *niger* |
| *Leucaena* | *leucocephala* |
| *Lotononis* | *bainesii* |
| *Macroptilium* | *atropurpureum, lathyroides* |
| *Macrotyloma* | *axillare, uniflorum* |
| *Mucuna* | *pruriens* |
| *Neonotonia* | *wightii* |
| *Securigera* | *varia* |
| *Sesbania* | *cannabina, grandiflora, rostrata, sesban* |

| Genera | Species |
|---|---|
| *Stylosanthes* | *capitata, fruticosa, guianensis, hamata, scabra, seabrana* |
| *Trifolium* | *semipilosum* |
| *Trigonella* | *foenum-graecum* |
| *Vicia* | *atropurpurea, sativa, villosa* |
| **OTHERS** | |
| *Morus* | *alba, indica, serrata* |

## FORAGES IN APPENDIX 1 OF THE TREATY

Apomixis is asexual reproduction by seed without fertilization and occurs in many grasses, which cannot be used in plant breeding.

Browse: tree foliage eaten by wild and domesticated herbivores.

Crop residues: the, for humans, inedible parts of cereals and pulses, straws, stovers and haulms that comprise about half the above-ground biomass of these crops; much of this can be converted into economic products by ruminants. Non-leguminous crop residues have a low digestibility and are often treated with alkali to increase intake by animals. They can also be ensiled.

Fallow grazing is where, during an uncropped phase in a crop rotation, a sward suitable for grazing develops spontaneously. This is still widespread in some Mediterranean countries where two or three years of cereals are followed by one or two of unworked fallows on which a legume rich sward, composed mainly of annuals, develops from the seed bank in the soil.

Fodder conservation is harvesting and storing forage, usually by drying as hay or fermentation as silage, for later use, not to be confused with conservation of forage genetic resources.

Fodder crops are grown on arable land for harvest as a whole crop for livestock feed. Many are also field crops, cereals and pulses; others are specialised forages. Cereal seeds are used as livestock feed in concentrate rations. Some forages are also used as green manures and cover crops. Forages are only grown where they are economically competitive with other crops within a production system.

Forage is herbaceous feed for herbivores with relatively low concentrations of nutrients and low digestibility in comparison to concentrate feeds (e.g. grain). Grasses and legumes are commonly found in grasslands or can be grown as forage crops, trees grow in agroforestry systems and crop residues in arable fields. However, grasses and tree leaves are also collected from open spaces, in and near forests, along road sides and the banks of canals. Forage is either grazed or browsed *in situ*, or can be cut to be ensiled for later use or fed fresh to tethered, penned or housed animals. Forages seldom represent a directly marketable product, except rarely as conserved products (hay, silage).

Grassland is the generic term for all grassy vegetation (pasture, extensive grazing lands, rangeland, etc.). Grassland is a land use, and must compete with crops, wildlife, forestry and recreation. Grassland is a vegetation type (c.f. forest) defined as ground covered by vegetation dominated by grasses with little or no tree cover. UNESCO (1979) defined grassland as land covered with herbaceous plants with less than 40 percent tree cover. White (1983) further defined shrubland as grassland with up to 10 percent tree and shrub cover and wooded grassland with 10 - 40 percent tree and shrub cover.

Natural grassland occurs in habitats that are too dry or too cold for trees.

Nomadic systems: generally used of pastoral groups thought to have no fixed base, but who follow entirely erratic rain storms.

Pastures or sown grasslands consist of or include improved species or cultivars. Management may include fertilization, drainage, irrigation and herbicide use. Pastures are important within commercial livestock and arable farming systems and since they compete with other crops for land and inputs must be economically viable compared to other crops, at the farm system level. They often form part of an arable rotation in mixed farming systems.

Rangeland is grassland and grazing land consisting of native or unimproved species, and includes savanna and tundra, whose management is restricted to grazing, mowing, burning and woody weed control.

Savanna is wooded grassland with less than 40 percent tree cover.

Transhumant systems: pastoral systems where people with their animals move between distinct seasonal pastures, usually at considerable distance or altitude from each other.

## LIST OF ACRONYMS

| | |
|---|---|
| ACIAR | Australian Centre for International Agricultural Research |
| CGIAR | Consultative Group on International Agricultural Research |
| CIAT | Centro Internacional de Agricultura Tropical, Colombia |
| CP | Crude protein |
| CSIRO | Commonwealth Scientific & Industrial Research Organization (Australia) |
| DEFRA | Department of the Environment, Food and Rural Affairs |
| DM | Dry matter |
| DNA | Deoxyribonucleic Acid |
| EMBRAPA | Empresa Brasileira de Pesquisa Agropecuária, Brazil |
| ICARDA | International Center for Agricultural Research In the Dry Areas |
| IEA | International Energy Agency |
| IGBP | International Geosphere-Biosphere Programme |
| IGER | Institute for Grassland and Environmental Research , UK |
| ILRI | International Livestock Research Institute |
| IMPACT | Information Market Policy Actions |
| IPGRI | formerly International Plant Genetic Resources Institute , now Biodiversity |
| LWG | Liveweight gain |
| PGRFA | Plant Genetic Resources for Food and Agriculture |
| SINGER | System-wide Information Network for Genetic Resources |
| TCP | Technical Cooperation Programme (FAO) |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| WSC | Water-soluble carbohydrate |