AGRICULTURAL METEOROLOGY

CAgM Report No. 57

Agrometeorology of Grass and Grasslands in Tropical and Sub-tropical Regions

by

Jaime Ruiz-Vega

(CAgM-IX Rapporteur on the Agrometeorology of Grass and Grasslands for Tropical and Sub-tropical Regions)

WMO/TD No. 614

Geneva, July 1994
"This report has been produced without editorial revision by the WMO Secretariat and distributed. Its distribution in this form does not imply endorsement by the Organization of the ideas expressed in the report."
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SUMMARY</strong></td>
<td>V</td>
</tr>
<tr>
<td><strong>I. INTRODUCTION</strong></td>
<td>1</td>
</tr>
<tr>
<td>1. Importance of tropical and sub-tropical grasslands</td>
<td>1</td>
</tr>
<tr>
<td>2. Objectives of the report</td>
<td>2</td>
</tr>
<tr>
<td><strong>II. THE TROPICAL AND SUB-TROPICAL ENVIRONMENT</strong></td>
<td>4</td>
</tr>
<tr>
<td>1. Boundaries of the tropics and sub-tropics</td>
<td>4</td>
</tr>
<tr>
<td>2. Grassland ecosystems</td>
<td>4</td>
</tr>
<tr>
<td>3. Climatology of Grassland Ecosystems</td>
<td>8</td>
</tr>
<tr>
<td><strong>III. EFFECTS OF METEOROLOGICAL FACTORS</strong></td>
<td>9</td>
</tr>
<tr>
<td>1. Distribution of species</td>
<td>9</td>
</tr>
<tr>
<td>2. Photosynthesis</td>
<td>11</td>
</tr>
<tr>
<td>3. Growth</td>
<td>12</td>
</tr>
<tr>
<td>4. Response to fertilization</td>
<td>14</td>
</tr>
<tr>
<td>5. Insect pests</td>
<td>15</td>
</tr>
<tr>
<td>6. Quality</td>
<td>16</td>
</tr>
<tr>
<td>7. Animal Performance</td>
<td>17</td>
</tr>
<tr>
<td><strong>IV. METEOROLOGICAL FACTORS AFFECTING SWARD FORAGE PRODUCTION</strong></td>
<td>18</td>
</tr>
<tr>
<td>1. Plant Population</td>
<td>18</td>
</tr>
<tr>
<td>2. Leaf Area Index</td>
<td>20</td>
</tr>
<tr>
<td>3. Sward structure</td>
<td>20</td>
</tr>
<tr>
<td><strong>V. METEOROLOGICAL ASPECTS OF MANAGEMENT FOR IMPROVED YIELD AND QUALITY</strong></td>
<td>22</td>
</tr>
<tr>
<td>1. Stocking rate.</td>
<td>22</td>
</tr>
<tr>
<td>2. Cultivar selection</td>
<td>24</td>
</tr>
<tr>
<td>3. Irrigation</td>
<td>26</td>
</tr>
<tr>
<td><strong>VI. CONCLUSIONS</strong></td>
<td>26</td>
</tr>
<tr>
<td><strong>VII. REFERENCES</strong></td>
<td>28</td>
</tr>
<tr>
<td><strong>VIII. ACKNOWLEDGEMENTS</strong></td>
<td>39</td>
</tr>
</tbody>
</table>
SUMMARY

This report consists of six chapters. In chapter I the importance of tropical and sub-tropical grasslands is justified on the basis of their geographical extent and the number of people living in these areas. The objectives of the report are also presented. Chapter II describes the limits of the tropical and sub-tropical environment, but no attempt is done to impose the criteria of isotherms as definitive. Six grassland ecosystems are proposed on the basis of ranges of temperature and rainfall and their climatology discussed. It would be ideal to build this report around the grassland ecosystems proposed, but the availability of data is critical. The effects of meteorological factors on the distribution of grass species, metabolic processes, and response to fertilization are dealt with in Chapter III. This group of items seems to respond more to the levels of available moisture than to temperature. On the other hand, insect pest damage, forage quality and animal performance, which are also included in this chapter, seem to be more closely coupled to air temperatures. The response of a plant community is expected to be different from that of a single land, therefore, the effects of some meteorological factors on sward characteristics are studied in Chapter IV. Chapter V is an attempt to integrate the information given in previous chapters into management actions for improved grassland production and forage quality. Finally, in Chapter VI, some general conclusions are given.
I. INTRODUCTION

Considering that animal production is important in meeting food requirements and in the economy of many countries, and that meteorological factors influence the productivity and quality of grasses and grasslands, the Commission for Agricultural Meteorology at its ninth session in 1987 decided to elaborate a study on the agrometeorology of tropical and sub-tropical grasses and grasslands.

Joint rapporteurs, one from India and the other from Mexico, were appointed. As India did not nominate an expert, the Rapporteur from Mexico, prepared the report for the Commission.

Climatic and edaphic factors combine to define a range of environments difficult to assess. The definition of specific grassland environments is useful for the purposes of research and extension. Therefore, it is necessary to define the environmental factors and ranges to be considered. Man, however, is the main forcing factor to be considered when grass and grassland improvement is sought, especially in developing countries.

1. Importance of tropical and sub-tropical grasslands

The grassland is one of the most extensive vegetation types of the world, as about 40% of the earth’s vegetative cover is grass (Temple, 1970). It can be found between the equator and the limits of permafrost at about 65° latitude. Tropical and subtropical grasslands, however, are limited poleward to a latitude up to 40-45°.

Tropical and sub-tropical grasslands with a four month or more rainy season are estimated at 1048 million hectares (Burt and Rotar, 1983), which represent 23% of the total area of Africa, America, Asia and Oceania (Rotar and t’Manetje, 1983).

The total population of the tropical and sub-tropical regions represents about 75% of the earth’s population. About 50% live in the tropical area, where the standards of living are low. Most of the developing countries are located in this area. Developing countries are characterized by their low industrial output, and the high contribution of agriculture to the national product.

In the sub-tropical areas there is both developing and developed countries. Some developed countries such as USA, Spain, Italy, Japan and Australia have part of their territory in sub-tropical areas. Developing countries with important grasslands include: Egypt, Iraq, Iran, Israel, Libya, Mali, Mauritius, Mexico, Morocco, Niger, Pakistan, Saudi Arabia, and South Africa (Figure 1).

The importance of grasslands is at least threefold. They
represent the habitat of many wildlife species. They protect the soil resource against both hydric and eolic erosion, increase soil's organic matter content and facilitate water infiltration. Grasslands also provide food and water for grazing animals which transform the dry matter into milk and meat.

The increasing demand for protein of high quality and the preference of animal products as the source (CIAT, 1986) demands more productivity of both natural and artificial grasslands. More than 75% of all domesticated animals are found in tropical and sub-tropical regions. Tropical and sub-tropical animal production, however, represents only 10-25% of the animal production of temperate zones (Weber and Patzold, 1988). Although theoretically the production of protein by field crops is more efficient, the production of meat is advisable in marginal land and in extensive regions. According to Rotar and t’Mannetje (1983), over 60% of the world agricultural land is non-arable and suitable only for grazing. The most practical means to use all this low quality roughage is through ruminant animals (Little, 1983). According to Mason (1985), in northeast Thailand the production of rice is marginal due to lack of rainfall, abrupt topography and excessively well-drained soils, suggesting that most of the land should be reverted to pasture.

2. Objectives of the report

The objectives of this report are:

a) To review and summarize recent and available literature on the effect of meteorological variables on the growth and development of Tropical and Sub-tropical grasses.

b) To define grassland ecosystems by ranges of the meteorological variables which determine plant responses to dry matter production and quality.

c) To recommend meteorologically-based management practices for the improvement of yield and quality of tropical and sub-tropical grasslands.
Figure 1. Tropical and sub-tropical regions of the world
(Adapted from Nieuwolt, 1977 and Trewartha and Horn, 1980)
II. THE TROPICAL AND SUB-TROPICAL ENVIRONMENT

1. Boundaries of the tropics and sub-tropics

The tropical regions of the world are astronomically bounded by the Tropics of Cancer and Capricorn at 23°27' latitude N and S, but there is no such a clear cut line for the sub-tropical regions. These could be better defined as a transition zone between tropical and temperate regions.

The 18°C isotherm seems an adequate criterion to delimit the tropics. Newvolt (1977) considered that regions within the 18°C isotherm for the coolest month as tropical. This isotherm shifts poleward by about 5-10° over North America, West Africa, the Arabic Peninsula and the Indian Sub-continent. It shifts equatorward by about the same amount over Eastern Asia. In the southern hemisphere there are similar shifts. In South Africa it shifts poleward, but equatorward over Australia.

According to Trewartha and Horn (1980), the tropical regions are bounded poleward by the equatorial limits of killing frost, or in marine locations, by the isotherm of 18°C for the coolest month. This seems a more realistic delimitation, as sea level temperatures area meaningless to plant production. They define the sub-tropical regions as those between the tropical ones and the isotherm of 8 months with an average temperature of 10°C.

According to t'Mannetje (personnal communication, 1992) for grasslands, the main criterion should be the dominance of 'C' grasses in the grassland and not the occurrence of killing frosts. In sub-tropical regions with summer rainfall the growing conditions are tropical, but killing frosts are present. On the other hand, the mediterranean climate do not have killing frosts, but rainfall occurs in the cool season. C3 grasses are dominant in both places.

2. Grassland ecosystems

Speeding (1971), adopted Moore's definition of a natural grassland as "a plant community in which the dominant species are perennial grasses, there are few or no shrubs, and trees are absent". He, however, considered that although grasses may be dominant, it does not mean that the number of grass species is greater than the number of other plant species. Also he pointed out that the presence of trees (Savanna) is determined by both management and environment. In Tanzania the distribution of vegetation species is related to soil patterns (Lamprey, 1979). Walker and Noy-Meir (1982), however, found that there is a single equilibrium of woody and grass vegetation which will tend to develop under any
particular set of soil and rainfall conditions.

Mather and Yoshioka (1966) pointed out that the degree to which the distribution of vegetation types can be explained by climate depends on the climatic factors considered. They stated that temperature and precipitation are by themselves poor descriptors of climate. In order to make these variables more indicative of the climate, they must be combined with an index which relates precipitation and water demands for evapotranspiration. They don't dismiss, however, the importance of non-climatic factors on the formation of vegetation types such as the savannas and the low latitude pine associations.

Strage (1980) has highlighted man as the dominant biotic factor in grassland ecosystems. In northeast of Thailand, where annual rainfall is above 2000 mm, savanna type vegetation prevails (Vorasoot, 1987). Thus, a more general definition, which would include all kinds of grassland (natural or artificial) would be: "A plant community in which the bulk of the herbage consists of grasses (Speeding, 1971).

An ecosystem is defined as "an open system comprising plants, animals, organic residues, atmospheric gases, water and minerals, which are involved together in the flow of energy and circulation of matter (Speeding, 1971). Thus, a grassland ecosystem is formed by the interaction of grasses with different plant and animal species in a particular environment. This is a very complex interaction which is difficult to study as the number of plant and animal species found is large. In the particular case of a grassland ecosystem the scope of the study could be limited to animal species of economic interest and to the plant species growing in a fixed range of environmental factors. On the premise that rainfall and temperature are the main environmental variables which condition plant species adaptation, grassland ecosystems could be defined starting with meteorological factors, then subdivided by soil factors and then by management. It is out of the scope of this report to include soil and management factors. Table 1 shows the proposed grassland ecosystems associated to defined ranges of annual rainfall and mean annual temperature.

The tropical-humid savanna is composed of perennial grasses and tall trees. This is a man-made ecosystem, which results from forest clearing for either agricultural or cattle rearing purposes. It is the equivalent to savanne-boisée in French. The main problems in this ecosystem are the rapid loss of soil fertility after land clearing and soil erosion because of the loss of the protective cover offered by the trees. The accelerated transformation of tropical forests to pastures is a serious threat.
Table 1. Grassland ecosystems in the tropical and sub-tropical regions of the world.

<table>
<thead>
<tr>
<th>Grassland ecosystem</th>
<th>Mean temperature</th>
<th>Annual range(°C)</th>
<th>Mean Annual rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer</td>
<td>Winter</td>
<td></td>
</tr>
<tr>
<td>Tro.-submniid savanna</td>
<td>25-27</td>
<td>25-26</td>
<td>1-3</td>
</tr>
<tr>
<td>Trop.-subhumid savanna</td>
<td>23-27</td>
<td>18-24</td>
<td>3-8</td>
</tr>
<tr>
<td>Mediterranean steppe</td>
<td>20-26</td>
<td>7-13</td>
<td>10-21</td>
</tr>
<tr>
<td>Sub-trop.-humid grassland</td>
<td>22-27</td>
<td>3-11</td>
<td>11-24</td>
</tr>
<tr>
<td>Trop. or subtrop. steppe</td>
<td>29-35</td>
<td>15-21</td>
<td>11-17</td>
</tr>
<tr>
<td>Monsoon or upland savanna</td>
<td>13-22</td>
<td>10-19</td>
<td>4-6</td>
</tr>
</tbody>
</table>

In the tropical-sub-humid savanna ecosystem the trees are smaller and some species may lose their leaves during the dry season. Soil water retention capacity is an important factor which determines if trees or grass prevail. Trees are found in deeper, soils and thorny shrubs of the leguminous family are found in the drier areas. In this ecosystem, biomass production decreases sharply during the hot-dry season, causing moderate problems of availability of forages.

The Mediterranean steppe is characterized by the presence of annual grasses adapted to grow under moderate temperatures and occasional frosts. Annual legumes are a significant component of this ecosystem. These grasslands are used for extensive grazing due to their low productivity.

Sub-tropical-humid grasslands are composed of annual and perennial grasses and deciduous tall trees. Grass growth is considerable to the extent that it has been called tall grass prairie.

Sub-tropical steppes are characterized by the presence of annual grasses of reduced growth. Creosote bush (Larrea tridentata) and mesquite (Prosopis juliflora) are found in deeper soil spots. In the tropical steppes other perennial species, such as acacias and cacti, are found. The most important limiting factor in both sub-tropical and tropical steppes is the lack of rainfall. Overgrazing has caused the degradation of this grassland ecosystem in many parts of the world, especially in developing countries.

The monsoon and upland savannas are composed of perennial grasses and legumes. Several perennial or deciduous tree and shrub species can be found. The relatively good climatic conditions in these regions has encouraged immigration, which results on high population pressure over the available land.

Figure 2 shows the relative top and root growth of the
Figure 2. Mean annual rainfall amounts changes from steppe to tropical-humid savanna and relative rooting depths.
different grassland ecosystems according to mean rainfall amounts per annum.

3. Climatology of Grassland Ecosystems

The ecosystems shown in Table 1 can be roughly matched to major climatic types, which makes easier their geographical delimitation (Table 2). The symbols used are according to Koppen (1936), but most climate types are according to Trewartha and Horn (1980).

Table 2. Correspondence between tropical and sub-tropical Grassland Ecosystems and climate types.

<table>
<thead>
<tr>
<th>Grassland ecosystem</th>
<th>Climate type</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical-humid savanna</td>
<td>Tropical humid</td>
<td>Am</td>
</tr>
<tr>
<td>Tropical-sub-humid savanna</td>
<td>Tropical wet-dry</td>
<td>Aw</td>
</tr>
<tr>
<td>Mediterranean steppe</td>
<td>Mediterranean</td>
<td>Cs</td>
</tr>
<tr>
<td>Sub-tropical-humid grassland</td>
<td>Sub-tropical humid</td>
<td>Cf</td>
</tr>
<tr>
<td>Tropical or sub-tropical steppe</td>
<td>Semiarid</td>
<td>BS</td>
</tr>
<tr>
<td>Monsoon or upland savanna</td>
<td>Warm-dry winter</td>
<td>Cw</td>
</tr>
</tbody>
</table>

"Am" climates are characterized by their relatively high rainfall and temperature, but there is a short dry season which lasts 2-3 months with average monthly rainfall below 60 mm. This is the climatic event which separates the seasons, as temperature remains high throughout the year. The high relative humidity creates sultry conditions which affect the performance of both man and animals.

According to Trewartha and Horn (1980), "Aw" climates are similar in temperature to Am climates, but the dry season is longer. Also, the annual range of temperatures is slightly higher than in Am climates, especially during the dry season. It is possible to separate three periods according to temperature and rainfall: the cool-dry season at the time of low sun, the hot-dry season before the rains begin, and the hot-wet season during the rainy season. Rainfall variability is also higher, and increases with latitude.

"Cs" climates have most of their rainfall during the low sun period, which is modest in quantity. The high sun period is characterized by warm to hot summers and plenty of sunshine. During the winter season, mild temperatures prevail, which accounts for large annual temperature variations. Rainfall amounts are usually insufficient to satisfy the evapotranspirative demand. There are occasional mild freezes during the winter season, but air temperatures rise above 0°C as the day advances.
Sub-tropical-humid climates ("Cf") are similar in temperature regimes to "Cs" climates, but different in rainfall amount and distribution. Rainfall is relatively abundant and well distributed throughout the year, but concentrated in the high sun period.

Tropical and sub-tropical semi-arid climates are characterized by their lack of rainfall. The little rain that falls is unable to compensate evapotranspiration losses. Temperatures show a wide range of fluctuations, both seasonally and annually. The daily range of temperatures usually exceeds these ranges. Because of the lack of tall and abundant vegetation, and the rapid daytime heating, dry regions tend to be windy. This increases water use.

Warm-dry winter climates ("Cw") are found in tropical highland regions (>1800 m). These have adequate rainfall, but up to 70% of rainfalls in the summer months, which causes a moderately large dry season in winter. Rainfall amounts increase with altitude up to 2500 m above sea level to decrease thereafter. Large diurnal ranges of temperature are a distinctive feature of highland climates as the thin air facilitates the entry of strong solar radiation during the day and the loss of heat by radiation at night. The annual range of temperature, however, is small.

The agrometeorology of grassland ecosystems is highly influenced by the climatic conditions of the region, but type and density of vegetative cover, as well as soil-moisture retention capacity, modify it to a great extent.

III. EFFECTS OF METEOROLOGICAL FACTORS

1. Distribution of species

Temperature is one of the most important factors that control species distribution. Data from Alaska, Guatemala, India, Japan, Kenya, Nepal, Northern Canada, Russian Federation, Tanzania, indicate that tropical and warm season grasses of the Eragrostoidae, Panicoideae and certain species of the Oryzoideae and Arundinoideae are found at less than 2300 m elevation. At higher elevations, in tropical and sub-arctic regions, no warm-season grasses are found (Kawanabe, 1981).

C₄ species require high solar radiation and temperature for best performance. These could be divided further according to the acid decarboxylation types into NADP-malic enzyme (NADP-ME), NAD-malic enzyme (NAD-ME) and PEP-carboxykinase (PCK) type species. In Australia, the native C₄ grass flora is estimated to be 57% NADP-ME, 32% NAM-ME and 11% PCK (Prendergast, 1989). NAD-ME species are dominant in 48
out of 73 state and territory sub-divisions, including 23 within the megatherm/mesotherm arid bioclimate, which covers about 80% of Australia. Most PCK species and many species of all types with a suberized lamella in their Kranz tissue were found within the megathermal seasonal bioclimate. A prior study had shown that the PCK anatomy species were most abundant in tropical-wet Australia, as well as in relatively humid coastal and sub-costal areas (Prendergast, et al., 1986). *Sporobolus virginicus*, a C4 grass found in cold coastal areas is freeze sensitive (LT50= -2.5°C), but avoids freezing through an underground organ (Straub and Gallagher, 1989).

In southwest Africa 95% of the grass species had the C4 photosynthetic pathway. Temperate C3 species were found only in the winter rainfall region. In the C4 species, malate formers were more abundant with increasing rainfall, while aspartate formers increased with decreasing rainfall. Within the aspartate group, the NAD-ME types dominated in areas of very low precipitation (Ellis, et al., 1980).

A species can displace another if the environmental conditions are optimal for it. *Melinis minutiflora*, an invading African species, has displaced *Trachypogon plumosus*, a native species, in Venezuela, through high photosynthetic rates and opportunistic use of optimum conditions of soil and rainfall. Where soils are poorer and rainfall lower, however, the native species prevailed (Baruch, 1986).

Some species may displace native ones from marginal spots. *Panicum laxum* has colonized grass-herb swamps in West Africa, after being introduced from tropical America. This species exhibited enhanced seed germination under flooded and low light conditions, and germination characteristics of weedy species (Cole, 1977).

The degree of tolerance to water stress is often related to osmotic adjustment in grasses. Buffel grass has shown to adjust osmotically, which enables it to maintain high hydration levels at low water potentials (Wilson and Ludlow, 1982).

In Mid-west Madagascar, under relatively high rainfall (1600 mm/year), topography determines the distribution of vegetation types through variations in soil and hydrological factors (Granier, 1979). *Hyparrhenia*-Heteropogon grassland prevails in high-lying areas; *Loudetia stipoides* on leached and compacted soils; *Brachiaria*-Leerisia-Panicum-Paspalum grassland in low-lying areas and *Hyparrhenia spp.* on colluvium and alluvium soils.

It could be argued that vegetation types develop in response to many factors (Mather and Yoshioka, 1966), but the
effect of climatic factors is often overriding. In India, a highly negative correlation was found between the percentage of C4 grasses and annual rainfall (Takeda, 1985). In dry regions the proportion of C4 grasses often approached 100%.

According to Sanchez (1976) the natural vegetation in the tropics is closely correlated to climate. In South America there is some 270 million hectares of Savanna type vegetation. These savannas can be divided in to well drained ("Cerrados") and poorly drained. The last sub-type is the result of a combination of low sub-soil permeability, which created flooded conditions well into the dry season. This condition favoured the growth of grasses as apposed to the growth of tropical forest (Cochrane, 1982). The same author reported that the "cerrados" are most common in the wet-season where potential evapotranspiration amounted to (WSPE) 900-1050 mm. Together with the wet-season monthly temperature, WSPE helped to explain the distribution of several vegetation types in tropical South America.

Gastó, et al. (1985) associated the "agostadero", a grassland, which can be grazed in the wet season only, with the climate types Bsh an Bsk in Latin America. Another local name of this vegetation type is steppe in Russia and dry pampa in Argentina.

Andreae (1980) recognized six vegetation formations according to the number of wet months in the tropical zone. The upper humidity limit for grasslands is 9 wet months (WM) and the lower 2 months. Between these extremes, the humid savanna has 7-9 WM, the dry savanna has 4-6 WM and the semi-arid shrubland steppe has 2-4 wet months. This classification is similar to one proposed by Uhlig (1965), cited by Andreae (1970), which also defines vegetation belts in the sub-tropics as determined by the number of arid months.

Thus, temperature and edaphic factors, together with species ability to optimize resource use, condition species distribution. This ability is physiologically determined through photosynthetic pathways and adaptive mechanisms.

2. Photosynthesis

Under non-limiting conditions, the amount of photosynthetically active radiation intercepted by the leaves is the main factor controlling photosynthetic rates (PR) in C4 grasses (Cresswell, et al., 1982). High temperature, however, affects PR, specially in C3 legumes. Ludlow (1980) found that in two legumes (Calopogonium mucunoides and Vigna luteola) light use efficiency declined linearly with temperature between 15 and 45°C, but in two C4 grasses (Festuca purpureum and Melinis minutiflora) light use efficiency was independent of temperature between 15 to 40°C, declining
rapidly between 40-50°C.

Tropical grasses are susceptible to low temperatures, but different species have different responses. In Japan, the reduction in daily maximum. PR due to lower autumn air temperatures occurred earliest in *Pennisetum clandestinum* and *P. purpureum* and was latest in *Setariasphacelata* cv. Narok. In winter, when dawn temperatures were 10°C, morning PR were suppressed in all species, but * Panicum milioides* was the least affected (Ito and Numaguchi, 1989).

In sub-tropical areas a mixture of tropical and temperate grasses can be used. In Japan a ratio between 6:4 to 7:3 of temperate: tropical grasses was optimum to minimize seasonal variation in forage production (Otsuki, et al, 1987). Nine out of ten cultivars of *Chloris gayana* tolerated mild winters in Japan (Kawanabe and Neal-Smith, 1979).

Net assimilation rate (NAR), an estimate of gross photosynthesis, decreased above 30/25°C day/night temperatures in 6 temperate grasses, while NAR of 8 tropical grasses still increased above the same temperature regime (Kawanabe and Neal-Smith, 1980 a). Nada (1980) reported that *Pennisetum clandestinum, Paspalum dilatatum, Setaria sphacelata* and *Cynodon dactylon* grew better at 20/15°C, while *Themeda triandra, Heteropogon contortus, Cenchrus ciliaris, Panicum coloratum* and *Bouteloua curtipendula* grew better at 30/25°C.

It could be stated that under non-limiting conditions the photosynthetic response of most legumes is dependent on temperature. It is known that C4 plants do not reach light saturation, while C3 plants do not increase PR beyond a radiation flux less than half the optimum for C4 plants. Also, the optimum photosynthesis is lower in C3 plants. The temperature response of temperate grasses could be determined by the occurrence of C3-C4 intermediates.

3. Growth

Growth, defined as irreversible dry matter accumulation, and evaluated often by relative growth rate (RGR), is closely related to light intensity and temperature. In an evaluation of 8 tropical, 6 temperate grasses and one arctic grass, most temperate species had higher RGR than tropical species at low temperatures, but the opposite was true for high temperatures (Kawanabe and Neal-Smith, 1980b). Maximum RGR for tropical species was achieved at 36/31°C day/night temperatures (0.25-0.35 g/g day-1), while the minimum RGR was at 15/10°C. Temperate and arctic species showed greatest RGR at 21/16°C-30/25°C. For temperate species the maximum RGR was 0.15 g/g day. Some species such as * Paspalum dilatatum* and *Panicum coloratum* had higher RGR at 15/10°C than other tropical species, while others like *Chloris*
gayana were insensitive to temperature.

Tropical species may respond more to night temperatures and light intensity, while sub-tropical ones to day temperatures (Burket, 1977).

In South Africa, the majority of restioids and C3 grasses grow more in the cool season, while C4 grasses tends to show a preference either to a summer growth season or an additional cooler growth season.

Temperature interacts with day length to produce different plant responses. The RGR of 4 tropical grasses was twice that of 4 temperature grasses (Sato, 1980). Both groups produced more dry matter and carbohydrates/unit of N accumulated in long days (14 h) than in short days (9 h).

At least for tropical grass species, the diurnal range of temperatures is important. An hybrid of Pennisetum americanum x P. purpureum showed a 20% reduction in dry matter production when grown at a diurnal range of 13°C in relation to a constant day-night regime (Kionis, et al., 1985).

The growth response of tropical and sub-tropical grasses to sub-optimal temperatures is related to winter hardiness and hardening (Kobayashi, et al., 1979). In three sub-tropical grasses (buffel grass c. Bilola, green panic cv. Petrie and Panic coloratum cv. Makarikariense), the critical mean day temperature (at which no growth occurred) was 12°C, while in Rhodes grass cv. Callide and kikuyu grass cv. Whinttet was 8°C. The critical night temperature, however, was <4°C in all species when grown at 20°C day temperatures. There was no hardening effects when susceptible species where grown at 4°C for 10 days, but net assimilation rates (NAR) and stomatal conductance decreased significantly (Ivory and Whiteman, 1978 b).

Even within tropical legumes there is a wide variation in optimum variations temperature for dry matter (DM) production (Kytamura and Nishimura, 1980 b). Trifolium semipilosum cv. Safari, Lotononis bainesi cv. Miles and Glycine wightii cv. Cooper had larger DM production at 20 °C while the optimum temperature for Stylosanthes humilis cv. Townsville, Desmodium intortum cv. Greenleaf, Macroptilium atropurpureum cv. Siratro, and Leucaena leucocephala was at 30°C.

Growth, as well as photosynthesis, are closely related to radiation flux and temperature, but thermoperiod is also important. The effect of longer photoperiods may be throughout a larger supply of radiant energy, which in turn increases photosynthesis and dry matter accumulation, specially in tropical grasses, which are mostly daylength
neutral.

4. Response to fertilization

Grass response to fertilization is precipitation dependent, specially N fertilization (Widenfeld, et al., 1984). Response to P fertilization is conditioned mostly by initial soil P levels.

It is known that legumes, which often are found in grasslands, respond mostly to phosphorus, as they are able to fix N\textsubscript{2} from the air. The response to phosphorus, however, is also rainfall dependent. Gillard (1983) found that Townsville stylo increased dry matter production in response to phosphorus only in years with above average rainfall (>640 mm). This genus, however, is considered to be adapted to low phosphorus soil contents (Little, 1983). Cocks (1988), however, believed that the productivity of marginal grassland in West Asia and North Africa could be increased 4-times by fertilization of legumes with 25-60 kg of P\textsubscript{2}O\textsubscript{5}/ha.

The important nutritional implication is that the presence of such a legume can provide a diet with a reasonably high content of crude protein and a relatively low content of phosphorus. Smith and Andrew (1985) found that max. growth of Macroptilium atropurpureum cv. Siratro, with adequate P supply, was achieved at aerial temperatures of 30-35°/25-30°C (day/night) when root temperatures were 30°C. Day/night temperatures of 25/20°C severely restricted growth, especially when root temperatures were maintained at 20°C. No significant effects of aerial or root temperature were found on optimum P amount for maximum yield.

Low inputs of superphosphate applied to native perennial grasses and Stylosanthes spp. in the semiarid tropics of Northwest Australia increased the liveweight during the wet season and losses during the dry season (Winter et al., 1989 a, b and c) reduced.

Higher producing pastures, Symbiotic N\textsubscript{2} fixation and N fertilizer account for the major input of N, while in systems of low productivity a symbiotic N\textsubscript{2}-fixation and rain-N are important (Steele and Vallis, 1988). In Warwick and Gayndah, Australia, medicago spp. increased associated grass yields as if 50 kg N/ha were applied (Clarkson, et al., 1987). In another location, where summer rainfall was low, medicago spp. had no effect on grass yields.

Urea-N losses can be correlated to rainfall. In a grass pasture at South-eastern Queensland, losses of Urea-N were larger when urea was applied to wet soil and rainfall during the next week did not exceed 1 mm. If rain was 5 mm or more, losses were much smaller (Catchpoole, et al., 1983).
The advantage of using urea as an N-source is its high concentration, but one must be careful to avoid volatilization losses in wet soils.

African millet (*Pennisetum americanum*) did not respond to N top dressing but to cutting height in Japan (Watanabe and Ishida, 1985). This could be related to soil fertility, but species response to cutting height should be acknowledged (Kuyama, et al., 1981).

Soil amendments may improve forage yields in low pH soils resulting from high rainfall or poor management. An increase of 30 ton FW/ha was obtained when 500 kg CaO/ha were applied to a temperate grass growing in a location with 2000 mm rainfall (Momonoki, et al., 1987).

Both N and P fertilization response are highly dependent on the amount of rainfall, other factors being constant. The limit of rainfall for an economic response to N applications may be about 700 mm per annum (Buchanan and Cowan, 1990). At lower rainfall regimes other nutrient sources, such as legumes and manure are likely to give more economic gains.

5. Insect pests

Insect pests are important in tropical and subtropical areas because temperature is not as limiting as in temperate regions (CIAT, 1976). The conditioning factor is thus moisture, which also determines the amount of food available.

*Spodoptera spp* are important pests of grasses in both tropical and subtropical areas (Sparks, 1979). In East Africa it was found that adult oviposition of *S. exempta*, leading to out breaks early in the season, was associated with rainstorms in January-March, but not in April-May (Tucker and Pedgley, 1983).

In the USA, the fall armyworm (*Spodoptera frugiperda*), can only overwinter in the mild climates of southern Florida and Texas, since it has no diapause mechanisms (Sparks, 1979). Its larvae are polyphagous, but maize, groundnuts, sorghum and Bermuda grass (*Cynodon dactylon*) are preferred. Cool and wet spring followed by warm and rainy summers favour population increases. Moving warm and cold weather fronts and strong winds aid adult dispersal and migration.

The desert locust may affect as much as 28 million km² in Africa and Southwest Asia during its periodic outbreaks. These outbreaks are related to above normal rainfall in desert regions, where they usually breed, and winds in excess of 16 km/h. Unusual rains favour egg laying and hatching as well
as insect survival. At their winged stage, the insects are carried by wind into convergence zones, causing the build-up of swarms of billions of locusts, which can ravage entire fields in a short time (Griffiths and Driscoll, 1982).

Watts, et al. (1982) consider that grasshoppers are the most destructive group of insects on rangelands as several species cause important losses worldwide. Therefore, successful outbreak forecasting is necessary. In order to achieve this, a more complete understanding of the interaction between host, weather, parasitoids, and predators is required. On the other hand, some insects such as armyworms, cutworms, sod webworms, and white grubs may have an important effect on long term rangelands productivity, but never have been studied in detail.

In tropical rainy climates, "el salivazo" (Hemiptera: Cercopidaeae) can cause severe damage to grasslands when meteorological conditions favour high relative humidity. Some species, such as Pangola grass are highly susceptible, but others, such as Brachiaria mutica are resistant to the insect. The yield potential of B. mutica, however, is low (CIAT, 1989). Management of the sward to decrease relative humidity, e.g. frequent grazing, may lower the severity of the attack.

6. Quality

Wilson (1985) points out that it is necessary to undertake cooperative studies in tropical grasses involving plant and animal scientists in order to increase the amount of high-quality dry matter (DM). The challenge now is to understand the factors controlling the amount of fibre in plants, its resistance to breakdown in the animal, and to apply this knowledge to improve animal production. According to Robbins and Bushell (1985) the quality of feeds (particularly N content), rather than quantity, is more important in increasing animal production.

In Puerto Rico, 10 tropical grasses had higher average crude protein (CP) content during the dryer months (Tergas, et al., 1988a). In Tolima, Colombia, however, Dichanthium aristatum showed lower CP contents during the dry season and the last month of the wet season, but DM digestibility was not different between seasons (Laredo and Anzola, 1982). Water stress reduced DM digestibility at the fifth leaf stage in two tropical grasses (Badé, 1982). In Kleingrass, however, only the stem fraction was affected, but in Bermuda grass both stem and leaf fractions were affected.

In the arid zone of Puerto Rico there were differences in CP content between D. annulatum (9.7% CP) and seven tropical grasses (11.3-14.0% CP). Overall, CP content was lower during the periods of maximum forage production (Tergas,
et al., 1988b. According to Van Keulen, et al. (1986), in years of favourable rainfall dry matter production is related to the availability of plant nutrients. Under such conditions, the concentration of the limiting element will reach some species-specific minimum value, which will determine its quality. On the other hand, under low rainfall, water will be the limiting factor and the element concentration in the tissue will remain well above the minimum value, which will increase forage quality.

It is be advisable to use fertilizers in order to supply the deficient amounts of a particular nutrient. In India, N-fertilization increased the digestibility and CP content of Pennisetum pedicellatum (Tyagi and Virendra, 1986), but only up to 120 kg/ha, which was determined by the availability of rainfall.

The association grass-legumes is a mean for increasing forage quality. The digestibility and intake of tropical legumes does not decrease as rapidly with age as in tropical grasses (Kretschemer, 1980), but a major constraint is the establishment and maintenance of such pastures, especially in low-rainfall high-temperature areas. The detrimental effect of high temperatures on digestibility of tropical pastures, however, is expected to be less for grass/legume mixtures than for grass alone (Wilson and Minson, 1983).

In general it is expected that DM digestibility decreases with increasing temperatures (Kutamura, 1986), but this may be restricted to certain ranges. In Panicum coloratum cv. 75 this trend was seen only in the range of 30/20 to 35/25°C day/night temperatures. At 40/30°C DM digestibility was higher (Bade, 1982).

In general, it is to be expected that lower forage quality to be associated with decreasing rainfall and increasing temperature. N and P fertilization should be applied according to the amounts of expected rainfall and proportion of legume/grass species. Economic returns may be higher in grass/legume mixtures were moderate amounts of these nutrients are applied.

7. Animal Performance

Meteorological factors, particularly temperature extremes, affect animal behaviour and production. Under tropical and sub-tropical conditions heat stress is common. Some of the main effects of heat stress are lower food and higher water intake, which results in lower weight gains and milk production (Montserrat, et al., 1989).

In Guadeloupe, young-male creole goats were evaluated under shaded and non-shaded conditions for 10 months. The
animals under shade had significantly higher food intake and carcass weight than those under the non-shaded treatment (Sergent, et al., 1987).

Heat stress prevention under extensive cattle production, such as goat herding, is more economical by providing shade through bush or tree planting, but tolerant breeds may be available in the future. Montserrat, et al. (1989), recommend to plant scattered trees of the deciduous genera, but point out that in areas where tree growth is not possible, artificial shelter must be provided.

Dairy cattle is more sensitive to heat stress. Extreme heat leads to decreased milk production and fertility. Tropical breeds, such as zebu and brahma are less sensitive to heat stress than European breeds (Griffiths and Driscoll, 1982). McCown, et al. (1981) found that in Tropical Australia Zebu cattle gained more weight than temperate-zone cattle during the wet season, and lost less weight during the dry season.

Under zero grazing the use of artificial shades has proven to be beneficial. In Oahu, Hawaii, mean daily milk yields of Holstein-Friesian cows under metal shades was 18.5 kg per cow, while for those exposed to the sun it was 14.5 kg per cow (Ingraham, et al., 1979).

IV. METEOROLOGICAL FACTORS AFFECTING SWARD FORAGE PRODUCTION

In this chapter information is presented in some detail about the effects of temperature, humidity, and light on plant population, leaf area index, and sward structure and how these effects are influencing forage production.

1. Plant Population

Temperature affects to some extent grassland plant population as it may condition seed production, survival, hardiness as well as seed germination. This is because grassland renovation depends on successful in situ seed production and germination.

**Stylosanthes hamata** cv. verano is a short lived legume whose persistence and sustained yield depends on continuous plant replacement from soil seed reserves. Seed yield is maximum at 31/24°C day/night temperatures, but warm conditions during flowering increased both seed production and hardiness (Argel and Humphreys, 1983).

In South-east Queensland the potential for buffel grass (**Cenchrus ciliaris**) renewal from seed in a 16-year old buffel grass-siratro pasture was evaluated (Hacker, 1989). In
spite of a production of 490–2300 fascicles/m², viable seed soil-reserves amounted only to 60/m². It was concluded that soil temperature was too low to break seed dormancy, which increased the chances of seed rotting and damage.

Seed dormancy may be the result of seed hardiness. In a study carried out in Japan, seed coat scarifications showed that the main cause of dormancy in tropical legumes was seed hardiness, but low temperature treatment also broke seed dormancy (Yoshiyama, et al., 1979). Species which gradually broke dormancy included *Stylosanthes humilis* and *Controsema pubescens*. Species showing repeatedly broken dormancy at short intervals were *Leucaena leucocephala* and lucerne, while *Macroptillium atropurpureum* and *Glycine wighti* showed this characteristic at longer intervals. The application of GA effectively broke seed dormancy in green panic, especially after harvest. The increased germination was maintained for one month if the seed was stored in a cool environment. Dormancy was not broken by storage for 3 years at 5°C and 45% RH. In order to obtain high field germination, however, a soil temperature of 25°C and soil surface packing after sowing were required (Ibaraki, et al., 1981).

Several tropical legumes have shown different optimum temperatures for germination (Kitamura and Nishamura, 1980 a). *Desmodium intortum* cv. greenleaf, *Macroptillium atropurpureum* cv. Siratro, and *Loteronitis bainessi* cv. Miles had optimum sowing temperatures above 25°C, while *Trifolium semipilosum* cv. Safari had optimum sowing temperatures below 25°C. *Stylosanthes humilis* cv. Townsville had optimum germination temperatures close to 25°C.

The establishment of improved pastures on existing swards is a practice that is likely to become popular, especially if efficient methods of planting are developed. In order to evaluate the effect of temperature on the establishment of temperate grasses (*Lolium multiflorum, Bromus catharticus*, and *Festuca arundinacea*) in existing subtropical grass swards (*Penisetum clandestinum* and *Paspalum dilatatum*) a research programme was undertaken (Hill, 1985). Seed weight persistence, tillering capacity, growth per tiller and seedling height were desirable traits in temperate grasses. Temperature effects were important on germination, pre-tillering seedling growth, rate of tiller production and growth per tiller. The rate of regrowth and recovery of existing pasture after spraying with herbicide was also related to temperature.

The seeds of *Themeda triandra* have the ability to bury themselves by a corkscrew motion as humidity changes, but seeds sown into stand of the unpalatable grass *Myxerella distichal* failed to germinate due to lack of rain in Germany. As the land received increased levels of preparation, however,
the number of *T. triandra* plants/m² after 12 months increased from 13 to 43 as level of preparation increased from cultivation to ploughing (Rommel, et al., 1988).

It can be concluded that seed germination and seed emergence are influenced by different factors. Temperature, seed hardiness and soil moisture may influence more seed germination, whereas seed size and soil physical conditions may influence more seedling emergence.

2. Leaf Area Index

In the next two paragraphs some references are presented about the relationship between temperature, water and leaf development in some grass species.

The rate of leaf appearance is closely related to temperature in many species. In seven tropical and sub-tropical grass species, maximum number of leaves was obtained between 30-33°C, but tiller formation was greater at lower temperatures (Kobayashi, et al., 1977). Although, in some species as Buffel grass cv. Biloela, Rhodes grass cv. Callide and *Panicum coloratum* var. makarikariense cv. Pollock, tillering is not affected by temperature (Ivory and Whiteman, 1978 a). The first and second species mentioned before had different optimum temperatures for leaf area development and for growth of the whole plant.

In two tropical grasses, reduction of tiller number/plant due to water stress was associated to a DM yield reduction of 38% (Bade, 1982).

Leaf area index is closely related to crop growth rate in many species (Evans, 1975). In the early stages of development, leaf area index and crop growth rate are small. Watson (1971) recognized that a faster leaf area accumulation could increase the efficiency of most crop production systems. Therefore, selection for large leaves, rapid leaf expansion and tillering is indicated.

3. Sward structure

Empirical attempts to explain in a general way some aspects to be considered for describing the structure of any kind of grassland and some practices related to structure and animal production are dealt with section.

The structure of a grassland sward is quite complex, specially if different species are present. According to Speeding (1971), the structure of individual plants determines whether they shade or are shaded by others, whether they are grazed or damaged by the grazing animals, and the plant microclimate. He points out that the parameters used for the
appropriate description of a sward structure change according to the aspect being considered. Height and density could be used, but are quite difficult to describe for a sward.

Since leaf area and leaf display are important components of sward structure, the light extension coefficient (Monsi and Saeki, 1953) could be used to characterize swards. This coefficient could be predicted by modelling for different conditions.

Although underground structure is still more difficult to evaluate, there is a relationship between the amount of dry matter allocated to shoots and roots. Most of the roots in grasses are located in the top 20 cm of soil. The relation root/shoot, however, is altered by weather related factors such as soil moisture and temperature.

Plants of Dallis grass, Setaria anceps and Panicum maximum var. Trichoglume grown at 15°C had a large number of tillers and high root/shoot ratio, which delayed growth, but increased temperature was able to increase growth rates again (Kobayashi, et al., 1979). Once the tillers were produced, their development was greater at higher temperatures and soil moisture in the tropical grasses Bermuda grass cv. Coastal and Panicum coloratum cv. 75 (Bade, 1982).

The structure of the sward changes according to the growth habit of the legumes present, which determines cutting frequency. In a mixture with Rhodes grass, bunch and creeping legumes such as Stylosanthes guianensis and Lotonois painesii were favoured by frequent cutting compared with climbing legumes such as Centrosema pubescens (Kytamur, 1983).

Selective clearance of woody components in savannas, which changes the sward structure, may increase animal production (Barnes, 1982; Burrows, et al., 1986), but knowledge of methods and effects of clearance is still inadequate. Animal species may respond different. In India, goats performed better than sheep when the rangelands had more bushes and trees (Pachauri, 1988).

In the semi-arid tropics of northwest Australia, killing the trees in a native perennial grass savanna Oversewn with Stylosanthes spp., did not affect legume yields, but dry matter yields of the grass increased 100% in the first 3 years (Winter, et al., 1989C).

Under extensive savanna exploitation, fire is a management tool that, even when causes serious losses of N, dry matter and legumes, removes the old grass and promotes regrowth of new grass (Spainin and Lascano, 1985). In Venezuela two burning experiments and two experiments on competitive interference between seedlings and adult plants,
showed that the highest mortality occurred during the dry season and was due to fire. Susceptibility to fire damage decreased as the plants increased in structural complexity of the cump, which gave more protection to the meristemes (Silva and Castro, 1989). Survivalship during the first year and after 3 years was dependent on the size attained by the end of the first growing season. Adult interference with seedling growth was mostly due to root competition but, foliage interference due to canopy structure could be important.

All sward structure components, namely: plant population, leaf area, leaf display and woody components affect overall productivity. It is necessary to increase modelling efforts aimed towards improving grassland management based on sward structure dynamics.

V. METEOROLOGICAL ASPECTS OF MANAGEMENT FOR IMPROVED YIELD AND QUALITY.

1. Stocking rate.

The stocking rate or carrying capacity of the land is highly dependent on rainfall amounts. In North Kenya, where rainfall showed extreme variability, it was advisable to graze at 50% of the maximum stocking rate for cattle, in order that adequate vegetative cover was left for soil and water conservation. Sub-desert riverine vegetation could carry 5-7 tropical livestock units/km² per annum and highland perennial grassland 46-60 units (Field, 1986).

At high stocking rates (6.0-8.0 animals/ha), rotational grazing with 1 week on and 3 weeks off produced higher liveweight gain than continuous grazing in Serdang, Malaysia (Chen and Otman, 1986). Less weed invasion and more legume persistence were also seen under rotational grazing. Using a lower stocking rate did not give differences, a situation also seen in southeast Queensland (Jones and Jones, 1989).

In tropical-wet location of Perú an experiment was conducted on a poorly drained clayey Paleodult. Green dry matter production (GDM) of two contrasting grass-legume pastures was evaluated under three stocking rates (2,3 and 4 animals/ha) and two rest periods (21 and 42 days). GDM was affected by the rest period, but not by the stocking rate. The higher stocking rate however, resulted in rapid degradation of both grass and legume as well as in higher soil compaction and low water infiltration. It was concluded that the use of pasture in high rainfall, clayey soil regions should be based on lower stocking rate and longer rest periods. (Reategui, et al., 1990).
The effect of soil compaction on water infiltration, however, may be more significant on years with below average precipitation, as water availability would be reduced (Linsday, et al., 1983). Periodic turnover of soil may improve water infiltration and water-holding capacity of the soil (Chia, 1983). The use of legumes in grasslands has proven to be an advantageous practice. According to McIvor, et. al (1983). Several animal production studies have shown that the introduction of a legume into native pastures often results in increased carrying capacity. Weber and Patzold (1988) believed that the low productivity of dairy cattle in Africa (500 kg/cow) and Latin America (1000 kg/cow) is mostly due to insufficient supply of plant protein. Therefore, the addition of fodder legumes is advised.

In a semi-arid tropical savanna of Australia, oversewing with *Stylosanthes hamata* cv. verano and fertilization with superphosphate, increased the carrying capacity up to 10 times and the cattle was finished in half the time required on native pastures (Eyde and Guillard, 1985).

Once dry, the legume may be considered as "standing hay" (Montserrat, et al., 1989), but occasional rainfall may cause spoilage. McCown and Gardener (1983) in Australia estimated the risk of rainfall damage to dry legumes and the probability of green grass availability.

The establishment of the legume in strips may be more suitable than in blocks (Tergas, et al., 1984). In Carimagua, Colombia, mean animal output obtained with a legume in strips covering 30% of the grazing area was significantly greater than that with the legume in blocks. The effect of complementary grazing on daily weight gains was significant only during the dry season. Soil fertility is also determinant of the carrying capacity of the land. In the monsoonal dry tropics of North Australia, with average rainfall of 640 mm, most of which occurs from December to April, Townsville stylo (*Stylosanthes humilis*) planted into native grasses, with tree clearing and Phosphate applied, decreased the stocking rate from one animal for 20 ha to one animal to 2.5 ha. However, the increase in cattle liveweight gains was not large enough to compensate for the cost of superphosphate fertilizer (Guillard, 1983). In Japan (Bade, 1982), found that eight tropical pasture legumes in mixtures with Rhodes grass produced an average of 16% more dry matter than the pure grass swards. The major contributions of the legumes are to prolong the period of liveweight gain and to reduce or eliminate dry season weight losses. Productive legume stands can be grown in dry tropical areas with at least 600 mm of rainfall per annum (Mc Ivor, et al., 1983). Increasing the stocking rate per unit increased N loss through retention, transfer, removal, N2 volatization and leaching.
Despite high N losses, animal excreta is important in maintaining high pasture productivity at high stocking rates (Steele and Vallis, 1988).

2. Cultivar selection.

The selection of adequate cultivar is important under both optimal and suboptimal conditions. A field experiment was conducted in the humid northern coastal plains of Puerto Rico to evaluate the production and persistence of 10 tropical grasses. *Panicum maximum* USDA PI 259553 was the most productive grass although not significantly different from *Digitaria decumbent* cv. Transvala, *Cynodon dactylon* cv. coastcross-1 and *Digitaria pentzii* cv. slenderstem. *C. nlemfuensis* cv. Star and *Panicum maximum* cv. Guinea were the least productive, while *Digitaria milanjiana* cv. Pangola Soto did not persist after a total of 20 grazing periods at 3 to 5 week intervals (Tergas, et al., 1988a). A similar trial was conducted in the semiarid region of Puerto Rico (Tergas, et al., 1988b). The behaviour of the cultivars was different during the first and second, drier, year. Makuenei and USDA PI 291047 were the most productive during the 1st year, and *Cynodon plectostachyus* cv. Star during the second year. Overall, Makuenei and USDA PI 259553 were the most productive. Thus, USDA PI259553 has a wide adaptation and is able to respond to increased rainfall.

In the central Valley of Oaxaca, a tropical dry region with a mean annual temperature of 21°C, *Chloris guayana* 141 produced the highest dry matter yield under limiting rainfall and soil conditions. During the first year, 1193 kg DM/ha were produced with 480 mm rainfall, while in the second year 961 kg DM/ha were produced with 340 mm rainfall. Species not adapted includes *Urochloa pollulans* 228, *Cenchrus ciliaris* 125 and *Eragrostis superba* 172, which yielded less than 300 kg DM/ha J (López, 1989).

In the cerrado region in Brazil, which contains half of the country’s cattle, introduction of higher yielding and drought resistant forage species was investigated. *Brachiaria ruziziensis*, *B. decumbent*, *B. humidicola* and Guinea grass were the most productive grasses with a production of 22-23 tons of DM/ha (Kornelius, et al., 1979). The response of legume species is also differential. In Belize, under a 1800 mm rainfall, four persistent forage legumes were evaluated in association with *Brachiaria mutica*. After 18 months of grazing at 6-week intervals the legumes and grass persisted, but the soil coverage decreased. The general ranking of the legumes according to soil coverage over the trial period was in decreasing order: *Macroptilium atropurpureum* (CF3-2), *Centrosema pubescens* (CF6-1), *M. atropurpureum* cv. Siratro and *C. pubescens* cv. Siratro and *C. pubescens* cv. Centro (Lazier, 1980).
Legume species such as *Stylosanthes hamata* cv. verano respond more to moderate applications of superphosphate than *S. Scabra*, *S. viscosa* and *S. humilis* (Winter, et al., 1989c). Without fertilizer, *S. scabra* cv. Fitzroy and Seca + *S. viscosa* mixture gave the highest wet season yields. *Stylosanthes hamata* and *Terammmus labialis* resist periodic overgrazing and *Leucaena leucocephala* can be highly productive in the dry season, but should not form more than 30-40% of rumiant diets because of its mimosine content (Keogh, 1980). In Central Queensland, however, mimosine toxicity has not been a problem when cattle has adequate amounts of grass (Wildin, 1985). As *L. leucocephala* exploits soil moisture and nutrients beyond the reach of grasses, it produces high quality forage when tropical grasses are not growing due to temperature or soil moisture limitations.

Cold tolerance is a desirable trait in sub-tropical regions. Early heading species and those species which remained green during the winter season showed cold tolerance at Miyazaki, Japan (Numaguchi, 1983). Some perennial legumes, such as *Macroptilium atropurpureum* and *Glycine wightii*, may survive in areas subjected to mild frosts (Russell and Webb, 1976).

Some species such as *Paspalum notatum* cv. Competitor are shade tolerant and could be suitable for agroforestry under humid sub-tropical conditions (Anon, 1987).

Variety selection should be done under animal pressure, as interactions between cultivar and stocking rate are likely (Jerez et al., 1987). It is customary, however, that the animal component enters in the last phase of the research process.

Burning is an event which may occur in grasslands, either by artificial or natural means. Natural fires are caused mostly by low rainfall and high temperatures. In regions where the incidence of natural fires is high, cultivar or species selection could be important.

Lourenco, et al. (1976) reported that in a Jaragua grass-tropical legumes mixture siratro and perennial soybean (*Glycine wightii*) showed greater resistance to burning than *Centrosema pubescens*. *Stylosanthes guianensis* (stylo) was the most susceptible species.

Thus, grass and legume varieties have to be adapted to tolerate a range of adverse factors. Besides being adapted to climatic, biotic and edaphic factors, a variety has to be adapted to the socio-economic conditions of the producer. Lack of infrastructure and economic constraints in the tropical Latin american lowlands call for a low input technology that can produce under both marginal and favourable
conditions (Toledo, 1985). A major component of this low input technology will be an adapted variety, but Shelton, et al. (1985) have warned about the low adoption of improved pastures in developing countries.

According to Martinez (1992), some additional criteria for the selection of species are: resistance to trampling, degree of soil protection against hydric and enolic erosion, easiness of establishment, and compatibility with other plant species in the plant community. He also points out that in arid and semiarid ecosystems it is better to improve the management of native grass species, rather than replacing them by introduced species. Only in more favourable grassland ecosystems it is advisable the partial or total replacement of native species.

3. Irrigation

In the sub-tropical areas, particularly in the subtropical dry and semi-arid grassland ecosystems, annual rainfall may not be enough to satisfy potential evapotranspiration. Application of supplemental water by irrigation may be beneficial, but close attention must be paid when selecting varieties, fertilization amounts and nutrients, and irrigation method, as profits may be marginal.

In Pretoria, South Africa, a comparison of tropical and subtropical grasses was made. Under supplementary irrigation, the subtropical grasses (Cenchrus ciliaris, Digitaria eriantha, Anephora pubescens, and Sorghum bicolor) produced 2-3 times more dry matter than the temperate grasses (Pestuca arundinacea and Agropyron x Triticum). The increase in dry matter yields due to irrigation was 150 % in the sub-tropical species (Grunow and Rabie, 1985), which maintained peak crop growth rates for 6-10 weeks longer in elation to rainfed conditions.

Response to irrigation is often related directly to the amount of water applied and could even amount to a quantity of N fertilizer applied. Clarkson, et al. (1987) found in Southern Queensland that grass yields in irrigated grass-medc pastures was similar to that of grass receiving 100 kg N/ha.

Irrigation during the low sun season may be more profitable, as the uncertainty of rainfall during the growing season may cause wasting water and money if it rains shortly after irrigating during the rainy season.

VI. CONCLUSIONS

The following conclusions represent an attempt to
summarize the more relevant findings of this literature review.

1. Grassland ecosystems are closely related to the climatic elements rainfall and temperature, the edaphic factor acting as a modifier through conditioning soil water retention capacity.

2. Grassland species dominance is determined by physiological responses to environmental factors, especially air and soil temperatures and rainfall amounts.

3. The differential response of C4 and C3 grass types to precipitation, temperature and light should be used to increase grassland productivity.

4. The use of grass-legume mixtures is an alternative practice to inorganic-N fertilization, but some P must be applied. This is a practice which could work in agroecosystems with moderate to low rainfall amounts.

5. Insect pest dynamics is closely coupled to meteorological factors, especially temperature and rainfall. This relationship could be used to implement weatherwise pest control practices. Using resistant varieties, however, is one of the more suitable insect-pest control practices in the grassland.

6. High temperatures are likely to lower forage quality, but grassland management can counteract this effect. One of the best management practices available is the association grass-legumes, but legume species must be carefully selected in areas of low rainfall.

7. Heat stress affects animal behaviour and performance in tropical environments, resulting in lower milk and meat production. Shading with leguminous trees or shrubs scattered on the more favourable spots of the grassland is a practical means to counteract heat stress as well as to improve the animal diet.

8. Optimal stocking rates are determined by rainfall amounts, soil types and animal species. Overstocking leads to resource degradation and to lower liveweight gains, but the socio-economic aspects of this problem have received little attention.

9. Besides being adapted to local environmental constraints, an improved grass or legume variety has to fit in the socio-economic environment of the farmer, which will ensure a higher adoption rate of the new variety.

10. Irrigation of grasslands must be done in conjunction with
good management practices, such as fertilization and rotational grazing.

VII. REFERENCES


Ibaraki, K., Koyama N. and H. Tokinaga. 1981. Cultivation practices for Green Panic, a tropical grass for haymaking,


Koppen, W. 1936. Das geographische system der klimate in Handbuch der klimatologie, Band I, Teil C. 1-44.


VIII. ACKNOWLEDGEMENTS

Special thanks to Professor Alassane M. Cisse, who made extensive and useful recommendations about the structure and content of the text, and to Professor L. 't Mannetje, who found the time to make several criticisms to this paper.

In México, Ing. Jorge López García and Dr. P. A. Martínez H. helped me in reviewing the draft, suggesting several improvements. I am very grateful for their observations.