AN OVERVIEW OF CHANGING SURFACE PROCESSES IN SEMIARID GRASSLANDS OF THE SAN PEDRO CATCHMENT NEAR CANANEA - SONORA, MEXICO.

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RESUMEN

Una cobertura vegetal es un sistema dinámico que evoluciona en el tiempo e en el espacio. Nuestras investigaciones se centrarán en las interacciones entre los procesos físicos y el comportamiento biológico de las coberturas vegetales a diferentes escalas espacio-temporales.

Con el fin de percibir la evolución de los estados de superficie (representada por el conjunto cubierta vegetal + suelo), la selección se llevará a cabo, a escala espacial, entre las características del suelo (nivel local) y las de la cuenca y, a escala temporal, entre la estación y la década. El funcionamiento espacial de los estados de superficie en las diferentes escalas temporales será igualmente considerado.

Para lograr este objetivo es necesario caracterizar las variables más importantes, en función de las diferentes escalas espacio-temporales, que deben considerarse para describir la evolución de los estados de superficie observada. De esta manera será posible analizar los mecanismos biogeofísicos que provocan ya sea la degradación, o la regeneración de los estados de superficie. Variables que deben considerarse :

- a nivel del balance radiativo: $Rn = Rs - aRs + Ra - \varepsilon\sigma Ts^4$

=> la evolución espacio-temporal de los términos del balance radiativo, modificados por las condiciones de superficie (aRs y $\varepsilon\sigma Ts^4$), permitirá evaluar el impacto de los cambios de estados de superficie en ciertas características de las masas de aire (temperatura nocturna, temperatura del suelo, energía disponible...);
=> la fracción de energía disponible Rn-G, debida a los estados de superficie, debe medirse correctamente con el fin de estimar con precisión los intercambios de evaporación LEv de los sistemas dispersos;

* a nivel del ciclo del agua

$$P = R + I + Ev \pm \bullet S$$

y del balance de energía :

$$LEv = Rn - G - H$$

=> la distribución espacio-temporal de las lluvias a escala del ecosistema (escala local) deberá conocerse detalladamente ya que los diferentes flujos de agua en el sistema unitario (distribución del escurrimiento en superficie R, reservas hídricas •S, evaporación LEv dependen de ella;

=> analizar conjuntamente la respuesta del ecosistema (evolución del sistema de raíces profundas, crecimiento de las especies dominantes del ecosistema...) y los intercambios LEv en función de las reservas hídricas del suelo •S para caracterizar los mecanismos que generan cambios en las interacciones.

* a nivel del ecosistema:
analizar la evolución espacio-temporal de la composición florística y llevar a cabo el seguimiento de la actividad biológica de los sistemas unitarios (producción de materia orgánica subterránea y aérea, índice foliar, grado de recubrimiento de la superficie del suelo y altura...), así como de las reservas de materia orgánica presentes en el suelo;

* a escala del transecto,
la transferencia lateral del agua de lluvia en el paisaje (paso de un sistema unitario a otro) constituye un parámetro importante que deberá evaluarse debido a la heterogeneidad espaciotemporal del medio (variaciones a gran escala de las reservas hídricas del suelo).

INTRODUCTION

The interdisciplinary Semi-Arid Land Surface-Atmosphere program (SALSA) aims at obtaining responses to the following questions (Goodrich, 1994):

=> what are the consequences of climatic and human-induced change on the water balance and ecological diversity in the Upper San Pedro River basin?

=> what are the effects of such change at event, seasonal and interannual timescales?

The Upper San Pedro River basin, near Cananea, in northeastern Sonora, has a large plateau surrounded by mountains that is of considerable interest for investigating poorly understood land-atmosphere processes, as the area is a patchwork of different biomes with heterogeneous land-use patterns. The basin is an ideal location (large plateau) to investigate :

1. the impact of anthropogenic change (e.g. overgrazing) with regards to desertification, sustainability and subsequent feedback effects on the regional hydrology and climate;

2. the effect of the summer season, under the influence of the "Mexican monsoon", on seasonal and interannual climate variability (desertification).

Responses to the main question were obtained by :

1. monitoring hydro-meteorological and ecological changes in order to determine seasonal and interannual variability;

2. investigating critical soil-vegetation-atmosphere exchange processes at different spatiotemporal scales.

The following strategy was adopted: low intensity long-term monitoring with intensive observations during the monsoon period at three biomes near Ej. Morelos in San Pedro basin. The programme included studies of meteorological parameters, micrometeorological measurements for radiation, water and energy fluxes, unsaturated zone soil moisture and vegetation biomass production within a nearly 5 km transect extending from the Huachuca foothills to the "mesa", integrating a variety of spatial scales. The transect is representative of the landscape in the San Pedro river catchment area.

The study aims at investigating temporal variability in surface radiation, water and energy exchanges, along with climatic forcing factors and surface conditions at differents sites representative of the landscape in the San Pedro catchment. The following presentation highlights the field activities during the 1996-1997 and some of the resulting datasets. The catchment area is described, in addition to climate, vegetation and soil characteristics. Some illustrative results obtained during the study period are presented. At this data-processing stage, we will draw some preliminary conclusions on critical desertification processes in this basin area. Complex interactions between forcing variables, such as solar radiation, precipitation and water vapour deficit, and the feedback effects of surface variables, such as soil wetness, soil temperature and vegetation gas exchange (evaporation), have to be analysed and parameterized before assessing their role in the global climate system.

2. THE CATCHMENT AREA :

2.1. Its description and climate

The Mexican part of San Pedro valley is located in the semiarid mountainous northeastern region of Sonora, comprising the headwaters of the generally dry San Pedro river. Four mountains enclose the semiarid plateau, i.e. Los Ajos on the eastern side, San Jose more to the north, Mariquita/Elena on the western edge, and Huachuca mountain near the national border. The town of Cananea is on the southern limit of the plateau, with Naco on the northern Mexican limit of the catchment area, at the Mexico-USA border.

The experimental study area presented here is located near Ej. Morelos. It includes a nearly 5 km transect located within a ranch at the Huachuca foothills. The slope of the terrain is 1-1.5%. The vegetation is characterized by a *Chihuahuan semidesert grassland*, and a typical mesquite grassland community on the upper part, with a variety of summer-active perennial grasses lower on the "mesa". In terms of the general physiognomy of this semidesert grassland, the native grasses generally have very short stems, with taller associated shrubby perennials.

Mexico is influenced by large-scale wind currents within the InterTropical Convergence Zone (ITCZ), and the climatic conditions prevailing in the country are markedly affected by shifts in this zone. The ITCZ represents the meeting point of dry cold air from the north and humid tropical air from south/southwest (Gulf of California) and south-east (Gulf of Mexico). Disturbances develop between the two air masses and give rise to storms and rainfall. The "Mexican monsoon" corresponds to the upermost edge of the ITCZ, affecting northern regions of Mexico, characterized by precipitation during a short period (3-4 months) in the summer, with the highest temperatures occurring just prior to the onset of rains.

In the northwestern region of Mexico as Sonora state, summer deep convective activities are mostly associated with tropical disturbances moving northward from the southwestern coast of Mexico, from the Gulf of Cortez, and from the tropical eastern Pacific coast. This results in high-speed surface winds (10-15 m/s), heavy rains, sometimes with hail, and flash flooding.

The northeastern region of Sonora state has two distinct wet seasons. Precipitation is more or less abundant from July to September, and represents 60-70% of the total annual average rainfall. Mean rainfall at Cananea (near Patos) is 462 mm/year from 1962 to 1981 compared to 287 mm/year at Naco for the same period. For a recent 6-year period (1990-1995), mean levels recorded at Patos and Naco are 446 mm/year and 204 mm/year respectively (fig. 1a for Patos and fig. 1b for Naco). The differences could be explained by the topographical position of Naco, i.e. just northeast of San Jose mountain and by the altitude of Patos (1550 m). Rainfall has a marked effect, with a reduction of 3-5° C in maximum temperatures in July (Fig.1.). This reduction is the impact of the land surface upon the climate characteristics through the partionning of the available energy : more evaporation and less sensible heat exchanges between the wet soil surface and the atmosphere. It is more pronounced at Patos due to higher rainfalls than at Naco. During the November to March period, precipitation is caused by movement of the cold air front, as indicated by the fluctuations in maximum and minimum temperatures. The vegetation is dormant during this period. The mean potential evaporation rate is 2200mm/year. The rainfall distribution associated with the overall temperature trend is responsible for the semiarid climate in this region.

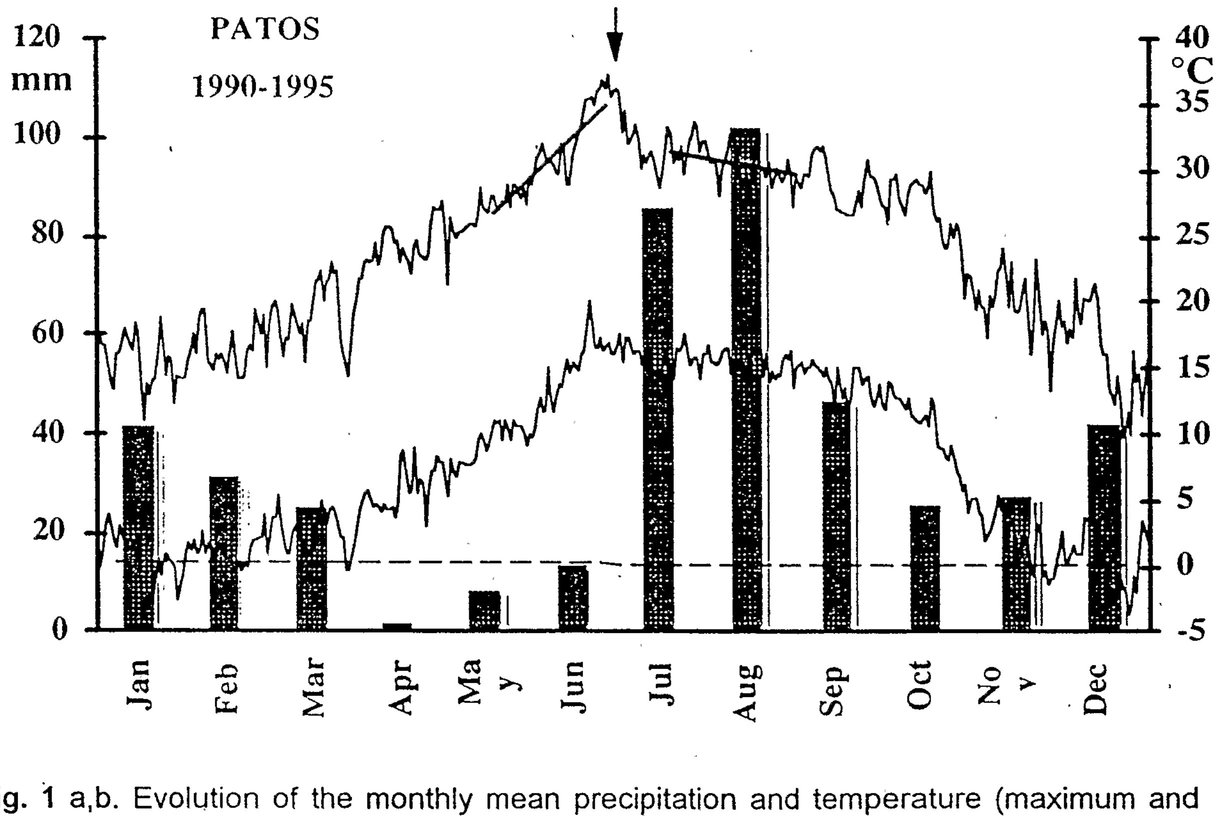

Fig. 1 a,b. Evolution of the monthly mean precipitation and temperature (maximum and minimum) at Patos and Naco from 1990 to 1995.

automatic tipping bucket raingauge station was installed and connected to a solid-state data logger to measure the quantity, intensity, duration and times of rainfall events. Both the temporal and spatial distributions of rainfall events were considered: nine other total recording raingauges were positioned at different points along the transect from the foothills to the mesa in order to determine the spatial distributions of precipitation.

Concerning soil moisture contents (S) at grassland sites, the position and stage of development of bunches of *Bouteloua* grass on the soil surface, the crusting of the soil surface and the microtopography may affect infiltration rates and surface runoff. The quantity of infiltrated water can vary between sampling points, and this has to be taken into account when calculating the site water budget. The soil water content was regularly sampled at the different sites.

The mean soil moisture content (4 samples) at each site gave us a global qualitative (but not quantitative) indication concerning the extent of surface runoff.

The soil-vegetation-atmosphere interactions can be apprehened through the different components of the energy balance. The evaporation rate corresponds to a convective exchange of water vapour at the interface between the soil-vegetation and atmosphere. This process needed energy to passe from liquide E to vapour λE. At a vegetated surface, for steady state conditions, when ignoring small storage terms, the energy equation can been written as :

$$Rn = \lambda E + H + G \qquad (Wm\text{-}2) \qquad (2)$$

where Rn : the net radiation flux density; G : the soil heat flux density ; Rn-G : the available energy at the surface which is used by turbulent transfer to the atmosphere as latent heat flux density λE (with E the evaporation and λ the latent heat of vaporization) and sensible heat flux density H.

As convective fluxes of heat and moisture to the atmosphere are highly dependent on surface conditions, the measurements were obtained throughout the "homogeneous" terrain with large fetch at the selected sites. Micrometeorological methods are well suited for measuring vertical evaporation flux over land surfaces without altering the surface environmental conditions. The Bowen ratio/energy balance (BREB) was used to measure evaporation and sensible fluxes over vegetated surfaces (for more details see *Monteny et al.* 1997a, Monteny *et al.* 1997b).

Radiation budget components were measured continuously from different biomes in order to efficiently assess the effects of surface properties on available energy. The radiation budget of the sparsely vegetated surface is :

$$Rn = Rs - Rr + \varepsilon\, Ra - \varepsilon\sigma Ts4 \quad (Wm\text{-}2) \qquad (3)$$

where R_n : the net radiation flux density; R_s : the incoming shortwave solar radiation, R_r : the reflected shortwave radiation (=aRs) with a : albedo; εR_a : the incoming long waveradiation and $\varepsilon\sigma Ts^4$: the emitted longwave radiation with σ = Stefan-Boltzmann constant, ε = the emissivity assumed to be equal to 0,94 for dry bare soil and 0,97 for the vegetated area and T_s : the surface temperature K°.

2.2 Its vegetation and soil surface conditions

Landform, topography, surface rockiness and soil type/origine have a direct effect on water availability through the redistribution of rainwater, i.e. the forcing factor for modelling the composition and structure of desert grasslands. In the San Pedro catchment, the landscape is gently undulating with low relief, and the physiognomy of the *Chihuahuan semidesert grassland* vegetation is as follows:

- the lower limit of the semidesert grassland is at 1200-1400 m elevation, forming a mosaic landscape with desertscrub;
- the semidesert grassland plateau or "mesa" (1300-1700 m) offers some landscape diversity due to the vegetation distribution, which is linked to rainwater infiltration rates, soil characteristics and the history of livestock usage;
- the upper limit, with evergreen woodland, is at 1600-1900 m elevation depending on the mountainside area

In the semidesert grassland ecosystem, there are summer active perennial bunch grasses, with the bases of the grass clumps separated by bare soil. The distance between bunches varies and therefore the patchiness of the surface, depending on the extent of grazing and the rainfall level. As this distance increases, due to a combination of low summer rainfall distribution (desertification process) and overgrazing (other desertification process), the bare soil surface increases. These factors alter the landscape physiognomy. The grassland is sparsely covered with C4 grasses and C3 annual grasses to a lesser extent. The mean grass height is about 15-30 cm on eroded gravelly upland sites (called dry *Bouteloua* grassland), and 40-60 cm in collecting runoff areas (called wet *Bouteloua* grassland) where the edaphic conditions are not as limiting. Shrubs (mesquite and other acacias) have partially colonized some other parts. The piedmont slopes have coarser soils and are dominated by a disturbed grass canopy cover of *Bouteloua* sp. and *Aristida* sp., in association with bushes such as *Prosopis* gl. trees and *Yucca*.

2.3. Its equilibrium state

The equilibrium state between soil-vegetation and the atmosphere in a region corresponds to the result of the interactions between the components of three main equations describing the radiation balance, the energy balance and the water balance (see schema). Example : the air temperature results of the partitionning of the available energy Rn-G between sensible heat H (air temperature) and the latent heat LE exchanges (air humidity) and the difference between incoming and outgoing long wave radiations (εRa - $\varepsilon\sigma Ts4$) ; the minimum air temperature measured at the end of the night results of the difference between incoming and outgoing long wave radiations.

Different components of the water balance were recorded. The most important is the water input over the area : precipitation P.

$$P = I + R + E + D \pm S \qquad \text{(mm)} \qquad (1)$$

with P : precipitation, I : infiltration, R : runoff, E : evaporation, D : drainage under the root zone and S : soil water content in the root zone.

Summer rainfall accounted for 60-70% of the annual precipitation. It is the most important forcing input variable in the vegetation cycle for all realistic climatic models. Rainfall quantity and intensity were accurately measured to simulate changes in soil surface properties as well as surface boundary conditions. We considered that this was the main physical factor affecting summer grass production from July to September. At each site, an

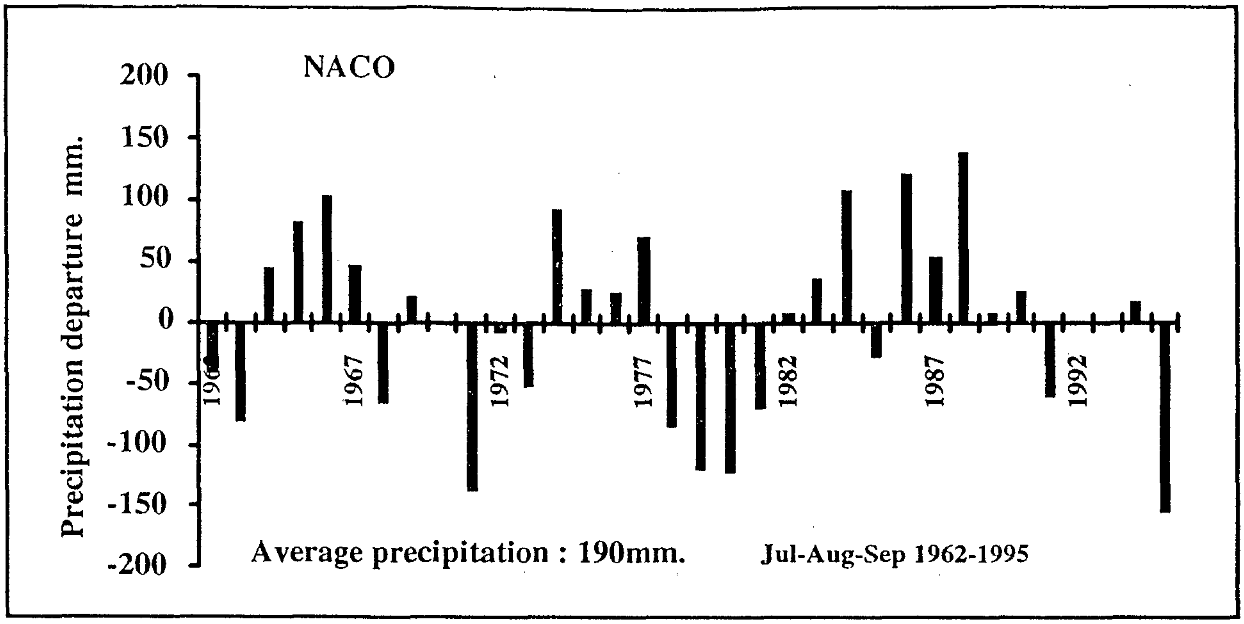

Fig. 3. Summer rainfall departures based on a mean of 190mm calculated for the 1962-1995 period at Naco.

3.1. Morelos site climatic characteristics (31°14'0942N; 110°15'4856W; alt. 1429m)

Routine, long-term monitoring of climate variables was undertaken at the Morelos meteorological station, which is located at Morelos, 35 km north of Cananea, in the San Pedro catchment. It is installed at the dry *Bouteloua* grassland site, in the middle of the transect. The weather parameters measured by the automatic station will be used as modelling components for this study, and to obtain complementary information on near surface climatic conditions prevailing in the northeastern region of Sonora, Mexico. Very little data from the climatic station is missing. Day-to-day variability in climatic parameters, such as solar radiation, temperature, or water vapour pressure, may conceal gradual trends from one type of regime to another with the movement of cold/dry or warm/humid air fronts. (see front in Fig.5.)

The effects of short-term irregularities can be reduced by a statistical technique, i.e. moving averages. The method involves calculating mean values for successive overlapping periods (5-day periods here). This smooths out the very short-term trends. Figures 4 and 5 give a overall view of the variations in climatic conditions during 1996-1997 as well as conditions prevailing during the intensive observation period (I.O.P.).

Figure 4 presents the evolution of the solar radiation Rs, a climatic forcing factor, and the climatic demand evaluated by the Potential Evaporation Ep. The daily potential evporation rate is calculated by a formula described by Lhomme (1998), based on the Penman equation. The increase of incident solar radiation affects the evaporation rate from January to July. We observed that Ep decreases drastically during the month of July from 12mm/day to 6-7mm/day in relation with the decrease of solar radiation Rs, due partially to clouds interception and to the increase of the atmospheric water content, represented by his dew point temperature Td (Fig 5). The reduction of the climatic demand (Rs and D) is related to the arrival of the "mexican monsoon" in the nothern region of Sonora. End of April, some preliminary rainfalls affected atmospheric water vapour content and the clouds reduced the quantity of solar radiation reaching the surface, affecting the Ep rates. High-speed winds prevailed during this period.

3. PRELIMINARY RESULTS

Annual and summer precipitation trends

The annual and summer rainfall departures, based on a mean for a 34-year period at Naco, are of considerable interest (Fig. 2, 3). It shows the varaibility of the rainfall input year to year in this region. The eighties present a wet trend, the nineties a drought one.

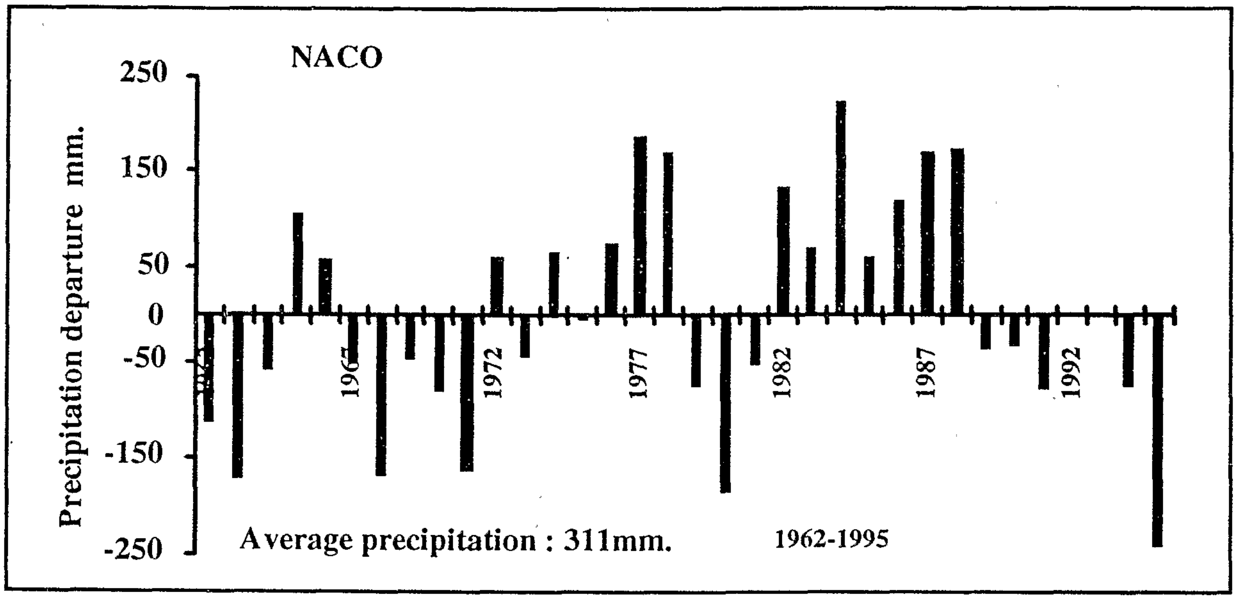

Fig. 2. Annual rainfall departures using a mean of 311mm calculated from 1962-1995 at Naco.

The cumulative impact of these successive annual droughts has resulted in a decrease of the water table level. In fact, the water table is principally supplied by the regular melting of the snow pack covering the mountains during the winter and the spring period. And in the nineties, the deficit of snowfall is well observed by the average minimum daily temperatures (Fig.1) which is anormally high for winter.

More interesting is the summer rainfall departures using the same period for Naco (Fig.3). It highlights the variability in precipitation during the summer in this semiarid region. There was also a wet trend through the 1980s, and considerable drought in the 1990s. The cumulative impact of these successive annual droughts in the 1990 was a decrease in grassland biomass production (personal communications of several ranchers). Although the general trend shows a decrease in total amounts of precipitation, spatio-temporal variability in rainfall events has to be taken into account, because this parameter is very important in this region as discussed later.

The sinusoidal trend for maximum and minimum temperatures reflected the general influence of solar radiation or, more specifically, the balance between absorbed solar radiation and the effective outgoing radiation during the year. Solar radiation is minimal during the winter period and maximum in summer due to the Earth's rotation. The marked maximum-minimum temperature fluctuations were due to an alternance of cold dry and warm humid air fronts. Cold dry fronts appeared from October 1996 until April 1997. They came from the north/northwest and were associated with a southward shift of polar air outbursts over the United States. Drastic decreases in air temperatures were observed, associated to cold/dry air fronts with clear blue skies. Increased air temperatures were due to airflows of more warm humid air coming from the southwest that lost part of their moisture over the mountains. The temperatures were above seasonal normal levels, as observed during the winter months.

Dew temperature (Td) monitors spells of cold/warm air and was generally 5-10° C lower than minimal temperatures, except when it rained. During the summer period, from July until the end of September 1997, dew point temperatures increased from -10/-7° C to approximatly +13°/+15° C. At this time, the northeastern region of Sonora was under the influence of moist southwesterly air masses. Summer rainfall comes with the advancing "Mexican monsoon". Dew temperature (Td) was almost near to the minimum temperatures, which means that fog could cover the catchment area, with dew on plant leaves in the early morning. This year, the rainy season began mid-July and finished mid-October. Rainfall peaked in August and cloud cover reduced incident solar radiation.

Mean potential evaporation rate Ep is evaluated to 2440 mm/year with an evaporation rate of 11-12mm/day in summer (May-June) and 1-2mm/day during the winter time, whereas the convective term represented 43% of the total yearly amount. In semiarid conditions, convective term (linked with water vapour pressure deficit D and high wind speed) plays the same important role as available energy in the general climatic demand represented by the potential evaporation rate Ep.

3.2. Precipitation / soil moisture availability

Long-term mean July-September rainfall (1962-1985) was 204 mm at Naco and 289 mm at Cananea. During the summer 1997, the rainy season was particularly short, with a total of only 224 mm of rainfall at our site in Morelos, mostly with amounts less than 5-8 mm and only eight large substantial events (>12 mm).

During the summer period, precipitation was mainly produced from convective cells initiated by surface heating, convergence and/or orographic lifting. Locally, thundershowers generally developed during the afternoon, due to a combination of high sensible heat fluxes at the soil-vegetation interface and advected tropical moist air from the south, mainly from the Gulf of California. During the period of July and August, one major phenomenon, associated with these convective clouds was lightning which was very prevalent during their development. Most showers were of light/moderate intensity because droplets generally evaporated before reaching the ground surface. The result was highly spatio-temporally variable rainfall and thus soil moisture contents. Large thunderstorms affected mean air and surface temperatures.

Another interesting phenomenon involved the formation of a type of convective cell moving with the wind that produced a streaky precipitation distribution, parallel to the wind direction. The following example indicates the effect of this type of cloud on rainfall

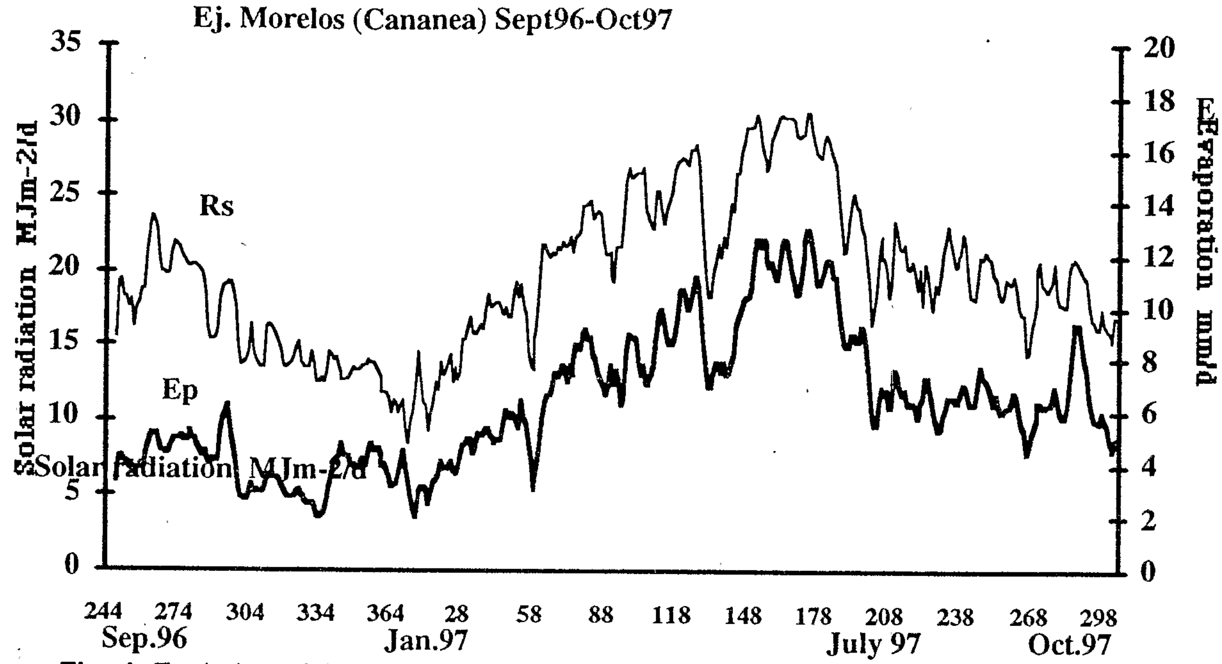

Fig. 4. Evolution of the incoming solar radiation Rs and the potential evaporation rate Ep at Morelos from September 1996 until October 1997.

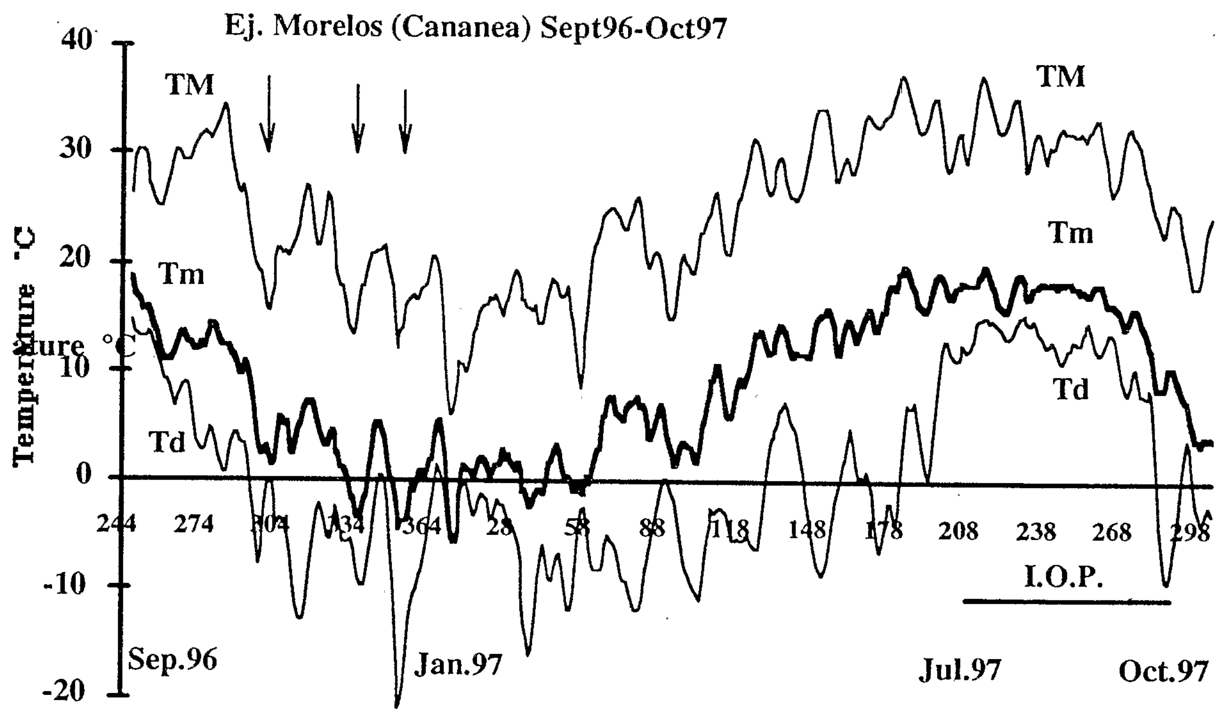

Fig. 5. Evolution of the maximum TM, minimum Tm and dew point Td temperatures at Morelos from September 1996 until October 1997.

The erosion of the surface soil due to these types of rainfall events leaded to a large number of gullies over the mesa area. <u>This is one of the most important process of desertification induced by a climatic factor.</u>

Rainwater inputs in this semiarid region are characterized by the type of clouds :
= many small amounts of rainfall (5-8 mm) throughout the area from convection showers, irregularly and scattered both in space and time, or from convective cells moving with the wind;
= some large events such as storms from cumulo-nimbus clouds, sometimes with hail; on such occasions, they can induce large-scale runoff, affecting water distributions at the ground surface and producing considerable surface erosion; it is one of the most important climatic factor disturbing the soil surface of a region;
= the period between events can be of considerable length and thus affecting the vegetation growth.

Soil water content and soil water potential are related by a exponential curve, but we have to adopt the concept of field capacity, representing the amount of water which a soil profile can retain against gravity and the concept of permanent wilting point which is the water content of the soil in which plants are wilted throughout the day. The water amount in between represents the storage capacity of the soil available to plants. But it is easer and more occured to measure the evolution of the soil water potential. The dynamics of soil moisture potential over time, obtained through the automatic measurement system installed at the *Bouteloua* site, are presented in Fig. 7. It shows the evolution of the soil water potential at different depths just after a rainfall.

The first day, rainfall was found to saturate the soil to approximately 20 cm depth. The soil water potential dropped to nearly zero, as measured the day after the event. The top 10 cm soil layer is characterized by a very rapid drying process : soil water potentials at 3-5 cm increase rapidly and more slowly at 10 cm. In less than 4 days, the first 5 cm soil layer was dry. The soil surface evaporation process was clearly observed and related to the atmospheric water vapour pressure deficit (D) (Fig. 7). The sinusoidal course of the soil water potential resulted from high climatic demand (Ep) during the day and an unsaturated flow supply from the lower layers. At night, when climatic demand was low, the soil was partially replenished with moisture from the underlayers and the soil water potential declined.

The water potentials could be converted to water contents using the moisture tension release charateristics. Soil water potentials of -0.01MPa correspond to a soil water content at field capacity of nearly 7-9% in the upper layer after percolation and 10-11% for 10-20 cm depth.

distributions : 12.5 mm of precipitation was recorded in the upper part of our transect, at the mesquite grassland site, while 37 mm was registred in the lower part, i.e. 5 km away in the grassland collector area. This level is threefold higher, and it occurred several times in the same summer, and subsequently affected grassland biomass production throughout the region .

Fig. 6 presents the evolution of 2 rainfall events : the first one was at the beginning of the summer rainfall season. The rainfall pattern is in the form of a monomodal dysimetric curve, with a high intensity rate at the beginning. The intensity was higher than the infiltration rate and produced runoff throughout the area. His impact was disastrous on the surface conditions : erosion affected all the area by discharging the unprotected soil surface. The infiltration rate, measured by the soil water content after the event, was only 55-60% of the rainfall amount. The second event correspond to a large outburst which passed over the whole catchment area. Wind from the south brings Gulf moisture to the region. This time, a large part falls in the mountains area. This kind of storm produced a large amount of runoff and flooding areas received so much discharge that the Rio San Pedro swelled quickly and water flooded over the bank of the riparian surfaces.

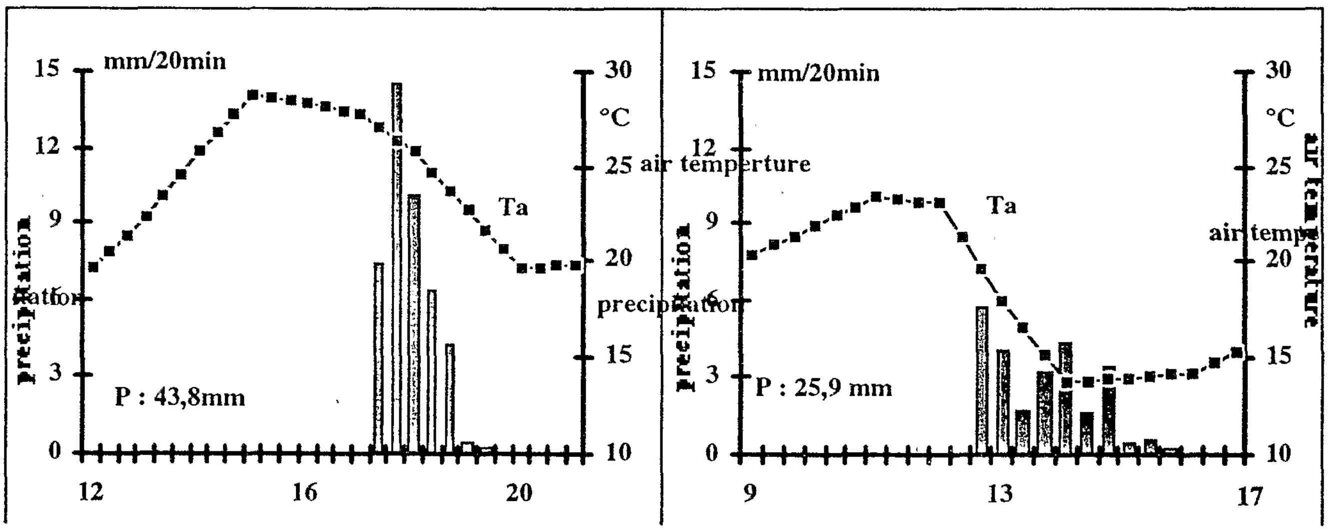

Fig. 6. Rainfall intensity for 2 events in 1997 associated with the evolution of the air temperature.

The *Bouteloua* grassland was found to have 15-20% soil coverage, with a sparse grass layer of different species dominated by *Bouteloua gracilis*, *B. repens*, *Aristida ternipes* and sometimes patches of *Hillaria belangeri*. The grass layer is mainly composed of perennial plants, mostly C4 species with a few C3 species. The grasses generally have an erected-leaf structure. The grass cover is more complete in the wet *Bouteloua* grassland, with a higher clump density. Annual C3 plants are very common in this part, thus representing an important element in the general physiognomy of the landscape.

Grassland production was measured in the fall using the following sampling technique: areal dry matter production was evaluated from the weight of biomass collected at 3 or 4 plots (1 m^2) at each site (Table 1). Grassland biomass production depends on the temporal and spatial rainfall distribution. When the rainy season started early and rainfall events were substantial enough to avoid long periods of water stress, the different species were able to grow "normally" to the seed production stage. In this semiarid region, the interstorm periods can be long enough to completly deplete the moisture in the top 20 cm of soil, where 80% of the root systems grow. The irregular rainfall distribution decreased the growth potential of the grass species as seedlings emerged.

Table 1: Areal grassland dry matter production (kg/ha) in relation with precipitation amount (mm) with or withoutlivestock in 1997.

	mesquite grassland	dry grassland bouteloua	wet grassland area
precipitation mm	**116**	**176**	**215**
Areal Biomass production			
without livestock	**0,650**	**0,780**	**1,350**
with livestock	**0,140**	**0,180**	**0,530**
potential without livestock		**1,140**	**2,040**

This year, the first rains of the summer season fell during two large storms occurring at 2-day intervals, which increased the spatial heterogeneity with respect to soil water availability in conjunction with the runoff process. Wet grasslands received more water in the lowlands. These communities have a higher growth potential, even with long drought spells, compared to other grassland communities growing on eroded gravelly upland sites. However this year, the wet grasslands did not receive sufficient runoff water. In the "mesa", these processes have led to a mosaic of different grassland habitats as seen in the biomass production (Table 1) which is a feature of this catchment area.

1. Soil water potentials near the surface (0-15 cm) varied consistently in response to individual rainfall events which were generally of short duration;
2. his sinusoidal evolution resulted from high climatic demand during the day and low during the night, with an unsaturated flow supply from the lower layers;
2. light rainfalls tend to recharge surface soil moisture whereas heavy precipitation produce more runoff and thus are less effective in soil moisture recharge;
3. the soil evaporation process predominated in the dry grassland ecosystem and the mesquite grassland community due to the presence of large bare soil surfaces;
4. in the wet grassland ecosystem, fluctuations in the soil water potential were less marked because of the vegetative soil cover and the quantity of organic matter present in the soil.

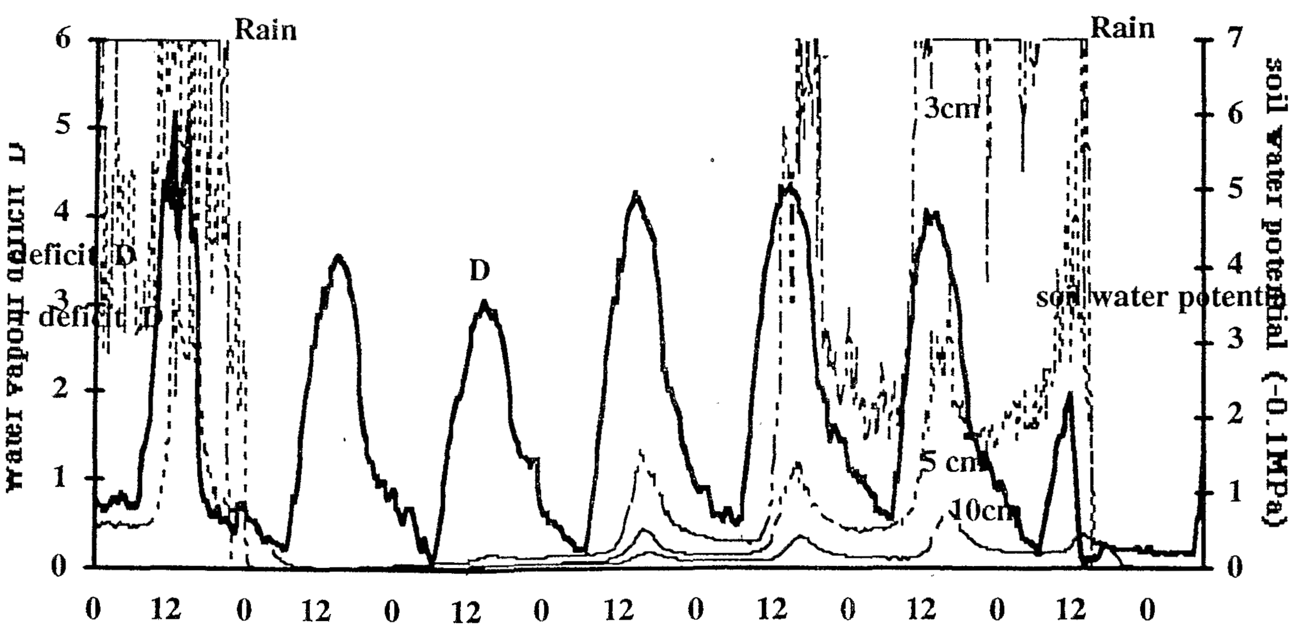

Fig. 7. Dialy cours of soil water potential beginning just after a rain which saturates the soil upper layers and atmospheric demand D.

3.3. Vegetation : biomass production (kg/ha)

Due to summer rainfall, 90-95% of the herbage biomass in the semidesert grassland (pastizals) is produced during July to September warm period. Table 3.1 gives some datas on the areal dry matter production measured at different sites in the transect relative to total precipitation.

In the summer period, the overall *Bouteloua* grassland albedo (Rr/Rs) was 22%, but varied according to the soil surface humidity.

The general albedo trend showed a progressive increase during the first 5 days, whereas the radiation budget pattern presented a more substantial decrease for both surfaces. The reduction was due to progressive drying out of the soil surface, which in return induced an increase in soil surface tempertures which can reache 60-65°C. The radiation budget decreased proportionally to increases in long-wave radiation loss. Surface temperature, through emitted radiation ($\varepsilon\sigma T^4$), affects the radiation budget Rn.

Surface properties affect the radiation budget. Surface soil moisture is the main factor affecting both reflected and emitted radiation. It is an important characteristic to be taken into account when analysing the impact of surface radiation characteristics upon climatic conditions in semiarid region.

3.5. Available energy (Rn - G)

It is essential to accurately determine the available energy in order to be able to precisely evaluate turbulent exchanges between the soil-vegetation surface and the atmosphere. This is one of the most difficult tasks when conducting investigations over sparse vegetation, even if net radiation and soil heat flux density are measured directly with sensors. For the purposes of this study, the mean soil heat flux was calculated by averaging data obtained from four soil flux plates dispersed over the grassland surface. For the radiation budget Rn, one sensor was positioned at 9 m height in order to accurately estimate net radiation.

The daily courses of net radiation did not differ for the two grassland surfaces at the outset of the observation period. (Fig. 9).

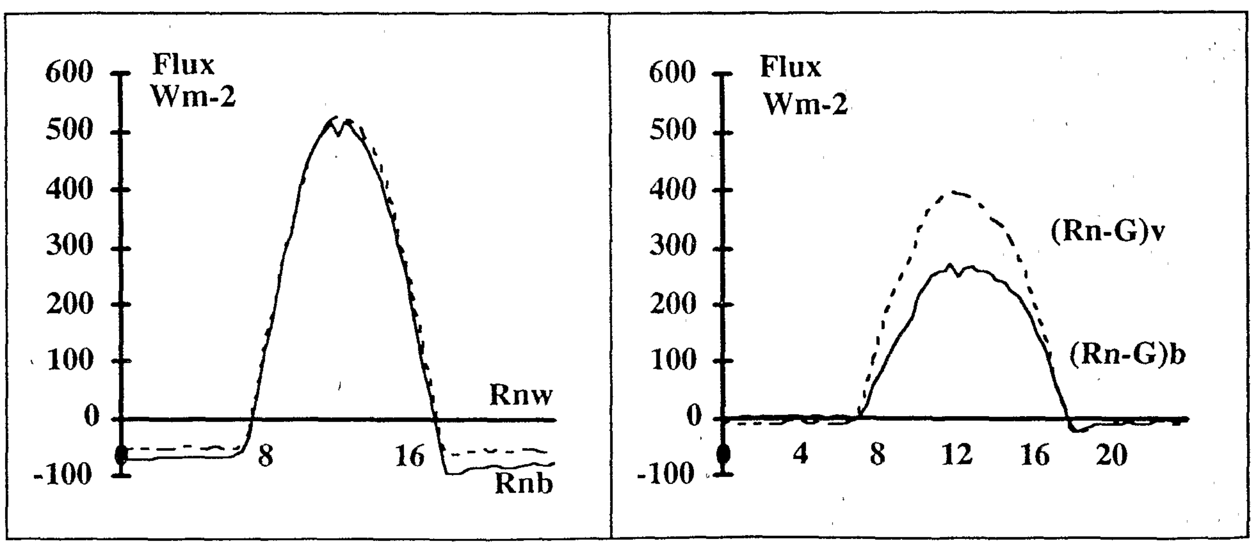

Fig. 9. Daily variations in net radiation and available energy for the two grassland ecosytems.(b : dry bouteloua grassland; w : wet grassland)

The two dominant grasses of the semidesert grassland (*Bouteloua gracilis* and *B. repens*) form a perennial grass-scrub dominated landscape on gravelly upland sites and in wetter areas. They are associated with other perennial and annual grasses. Their growth dynamics, influenced by rainfall patterns, account for the physiognomy of the grass layer. Redistribution of rainwater through increased runoff has had an important role in the development of the physical environment. The dynamics of moisture contained in the top 20 cm of soil has to be taken into account when assessing grass growth processes, and thus in the evolution of the ecosystem. Total areal biomass production differed between years in relation to rainfall events and to the redistribution/infiltration of runoff water in the soil. For the same total amount of precipitation in summer, biomass production can be completely different due to the differential dynamics of plant species induced by the distribution of rainfall events during the wet season.

3.4. Radiation budget over sparse grassland vegetation

The net radiation is affected by radiative surface properties as reflected and emitted radiation. Figure 4.4. presents temporal evolution of incoming solar radiation Rs, reflected radiation Rr, the emitted radiation and atmospheric radiation as well as radiation budget Rn (Fig. 8).

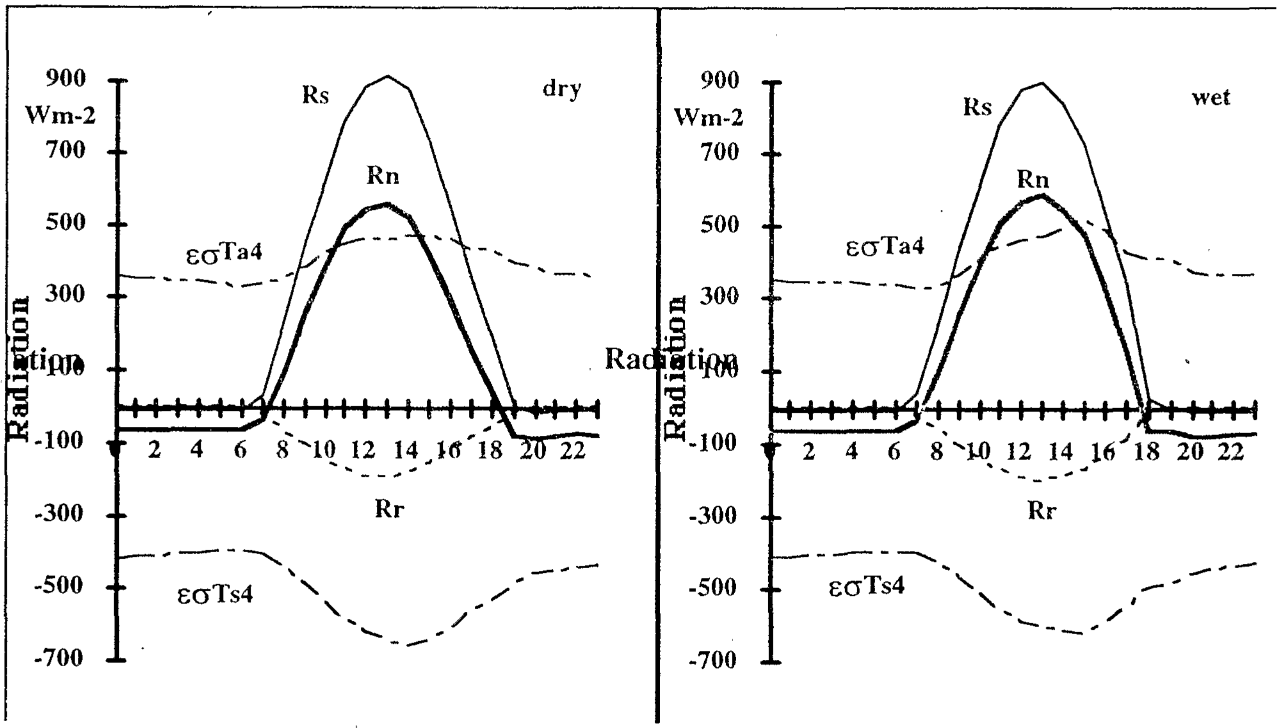

Fig. 8. Variations of the different componens of the radiation budget over two grassland ecosystems.

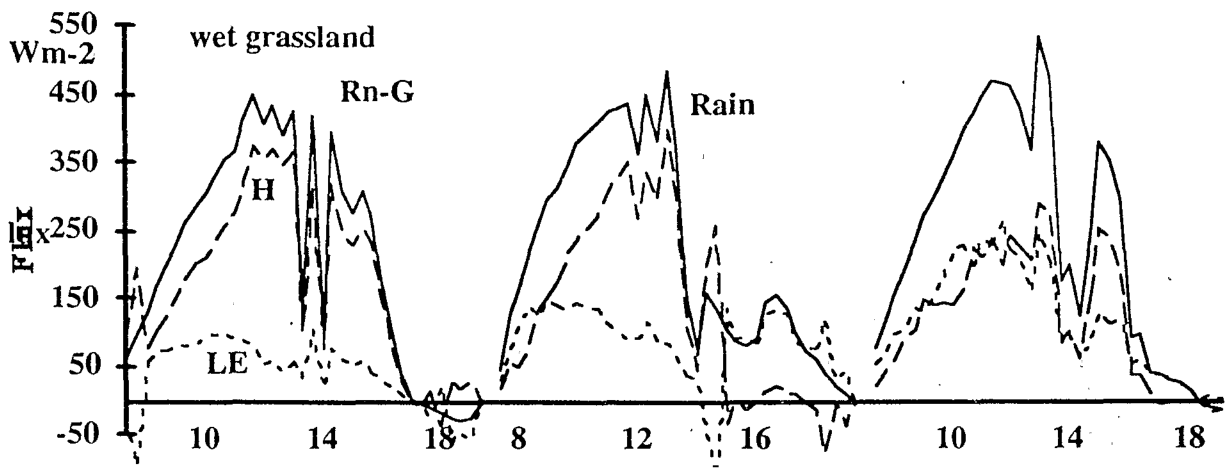

Fig. 11. Diurnal variation of the available energy Rn-G, latent heat LE and sensible heat H over a wet *Bouteloua* grassland.

Daily levels of available energy (Fig. 10) measured over a 15-20% covered soil were less than over a more densely vegetated surface (Fig.11), thus confirming earlier results. Just after a rain of 4 mm, latent heat was nearly equal to the available energy.

Most of the latent heat flux was considered in terms of soil evaporation at the onset of the vegetation growth cycle at the sparsely vegetated grassland. Over time, the evaporation rate quickly dropped while the sensible heat increased.

The evaporation reduction was less marked at the wet grassland site in relation to the vegetation cover (Fig. 11). It was not possible to measure nocturnal latent heat flux densities due to the weakness of the water vapour gradient, which was the same magnitude as the sensor error.

After 30 days, areal biomass production increased differently at the two sites. Variations in available energy and its partitioning into latent and sensible heat over the two distinct vegetation surfaces for 13 days, are presented in Fig. 12a,b. The figure presenting the data began just after a rain. There was a noticeable effect of the vegetative cover on available energy Rn-G and on the latent LE and sensible heat components.
This highlighted (Fig. 12a,b) :

= higher available energy in the wet vegetated area as compared to the dry *Bouteloua* grassland site;

= a steady decrease in the latent heat flux during the first days after a rain event, which was more marked over sparse *Bouteloua* grassland than over the wet vegetated grassland area. Sparsely vegetated surfaces dried out faster than the vegetated surface;

= when dry, the bare soil surface offered much higher resistance to water vapour transfer to the atmosphere, and most of the available energy was converted to conductive soil heat flux and to convective sensible heat flux. At the wet vegetated grassland, after the first days, available energy was almost equally partitioned between latent and sensible heat fluxes at this stage of grassland growth;

The surface charateristics at this time were very similar. However, available energy (Rn-G) differed due to the high soil heat flux G. The daily soil heat flux density was higher at the sparse dry *Bouteloua* grassland, consequently reducing the available energy of 25-35% compared to the other grassland site where some dry vegetation was still present.

In semi-arid conditions, it is essential to accurately measure the radiation budget Rn and the convective soil heat flux G due to the presence of large bare soil areas. The available energy (Rn-G) of a sparse dry grassland can be 40% less than that of a more densely covered grassland. This reduction in available energy is very significant in the partitioning of sensible and latent heat fluxes.

3.6 Soil-vegetation-atmosphere interaction.

Surface fluxes of latent and sensible heat were measured using Bowen-ratio energy balance stations. However, prior to the intensive measurement period in this study (IOP), performances of the different instruments-sensors were tested and then the Bowen ratio stations were compared for 2 weeks at the Sonora Agricultural School near Hermosillo. The stations were located in close proximity in the same alfalfa field. The results of analyses of data collected with both devices to evaluate sensible and latent heat fluxes during the alfalfa growing period closely agreed. The devices were then installed in June 1997 in the field near Ej. Morelos and flux measurements began just after the first rains, at the onset of the grass growth cycle. Figures 10 and 11 present variations in energy flux densities measured over two different grasslands before and after a rain event.

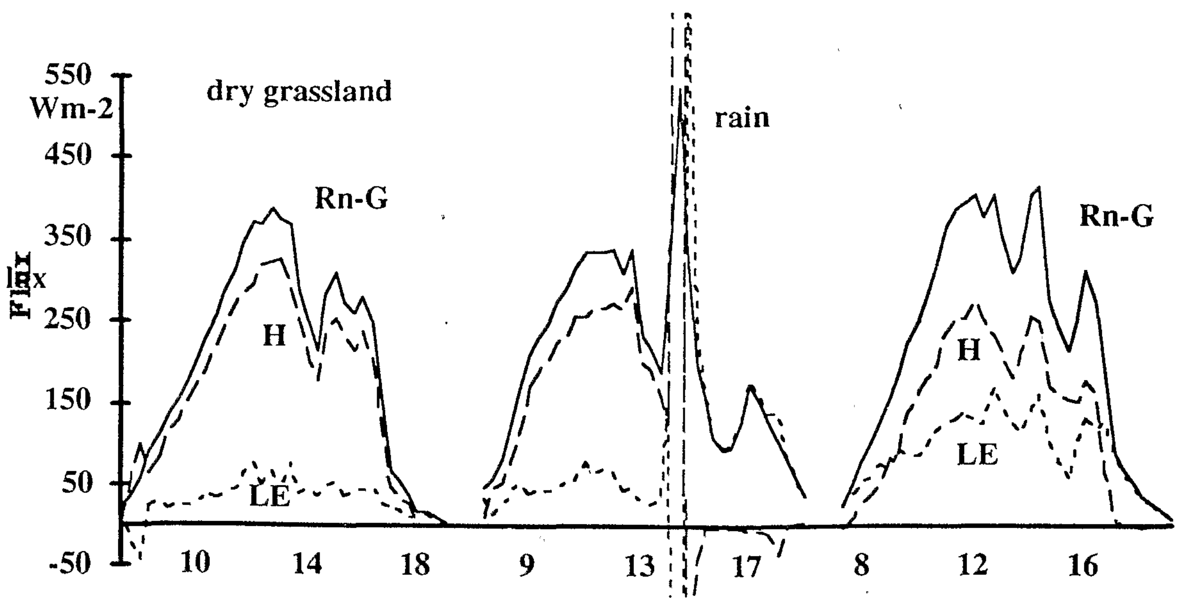

Fig. 10. Diurnal variations in available energy Rn-G, latent heat LE and sensible heat H in a dry *Bouteloua* grassland.

Daily levels of available energy (Fig. 10) measured over a 15-20% covered soil were less than over a more densely vegetated surface (Fig.11), thus confirming earlier results. Just after a rain of 4 mm, latent heat was nearly equal to the available energy.

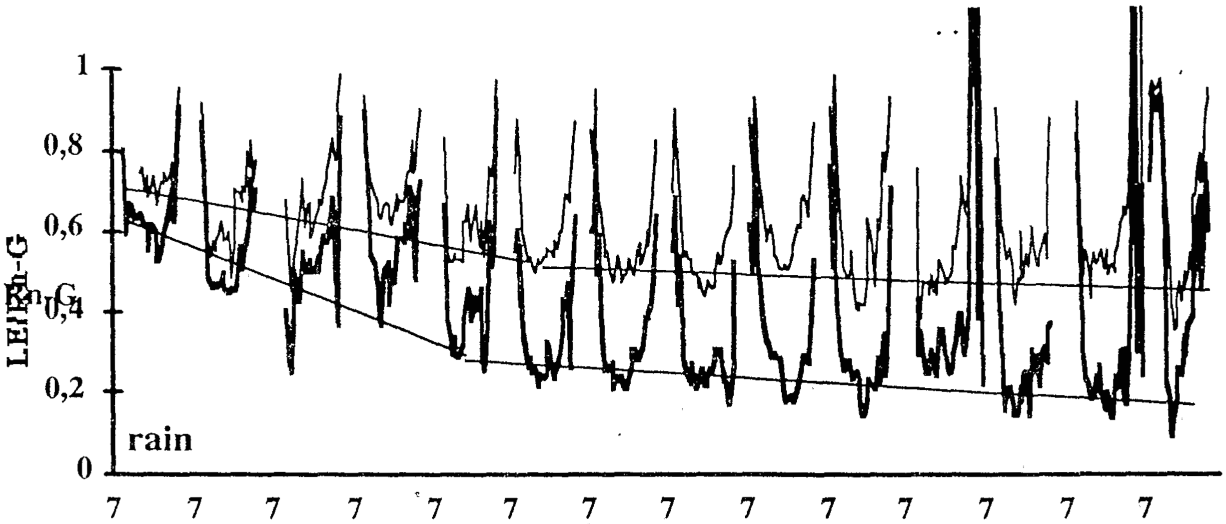

Fig. 13. Evolution of the évaporative fraction over two distinct grassland surfaces for 13 days after a rainfall.

The EF levels started at 0.65-0.7 just after a rain and decreased progressively to 0.50 for the wet grassland and to 0.30 for the dry grassland. This corresponds to the soil-surface related decrease in the evaporation process, and evaporation was more a vegetation process thereafter. The difference between the two grassland surfaces was attributed to the difference in areal biomass and to the soil water content.

The ratio of the areal evaporation ET of the grasslands to the potential evaporation ET/Ep is generally less than 0,50 for this year. It is less pronounced in the wet grassland area due to the growth and coverage of the grass layer in relation to the water availability.

Observed differences in sensible and latent heat fluxes over the semiarid grasslands were due to:

1. **higher available energy levels at the wet vegetated grassland site than at the dry grassland site;**
2. **the soil moisture content and stage of growth in the wet grassland promoted higher evaporation rates for a longer period of time;**
3. **low evaporation rates were related to the low level of water infiltration into the soil and to the patchiness of the grass cover;**
4. **high surface temperatures were recorded a few days later after rainfall; the wetness and drying out cycle induced the formation of a crust at the soil surface, thus affecting the seedling and soil fauna dynamics, as well the water infiltration rates;**
5. **the impact of the land surface upon the climate characteristics through the partitioning of the available energy is well marked at the start of the wet summer period : more evaporation and less sensible heat exchanges between the wet soil surface and the atmosphere. The maximum temperature is less in July than during May-June period.**

= evaporation (in mm/day) was twice as fast at the wet grassland in comparison to the dry *Bouteloua* grassland, which was related to the density and leaf area of the vegetation, available energy and the soil water content. The total amount of water returning to the atmosphere during this period was 25 mm in the wet grassland, compared to 13 mm at the dry grassland site during the same period.

After 4-5 days of drying out, the surface temperature of the sparsely vegetated area progressively rose to a higher level than that of the vegetated surface. This increase was related to the reduction of soil evaporation, while vegetation evaporation remained relatively constant. The air to surface temperature difference highlighted that the surface temperature could range from 15 to 20° C and drop by 5-10° C at night. This is an important parameter for understanding how grasses can adapt to wide diurnal temperature fluctuations, particularly concerning the growth dynamics of young seedlings. It is also a very important factor for termites, which have an important role in the soil structure as well as in the redistribution of infiltrated water through tunnels in the soil.

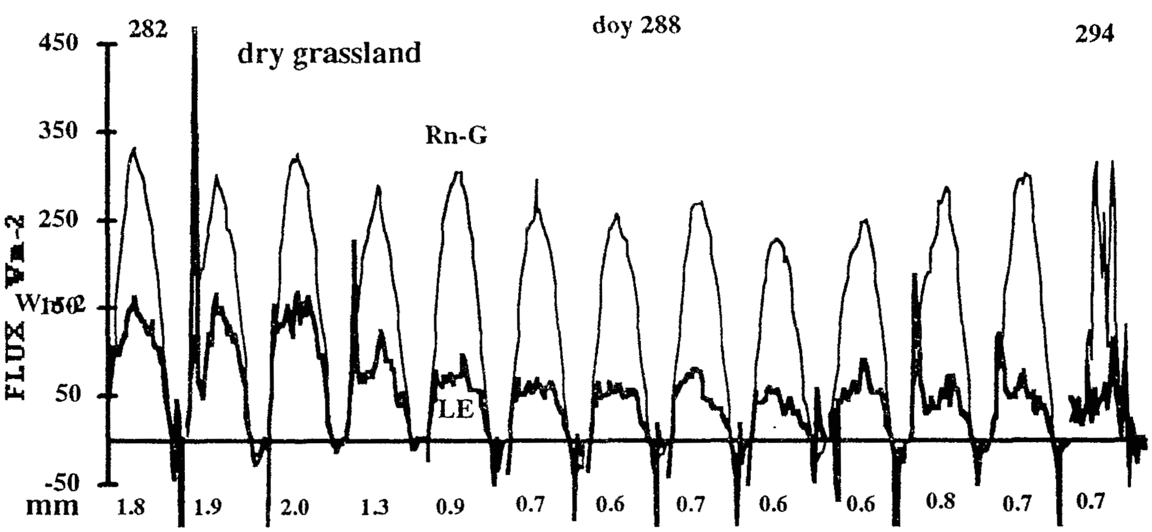

Fig. 12. Evolution of 2 energy balance components over a dry and wet grassland area. The daily total evaporation rate is given in mm/day.

Variations in the evaporative fraction LE/(Rn-G) = EF in the two grassland ecosystems provide insight into the partioning of available energy, as represented by a ratio between the evaporation rate (LE) to the available energy (Rn-G). It is generally acknowledged to be constant around midday. Daily variations of EF can be attributed : 1. to advected energy which alters the partition of available energy and 2. to clouds which affect net radiation.

CONCLUSION

Our preliminary evaluations about the interactions between soil-vegetation and climate are :

1. Effects of climate on the degradation of the surface characteristics caused by climatic variability :

* precipitation characteristics modify the hydrological budget :
  = for the same amount of rainfall, the intensity of rainfall can lead to more runoff which accelerates the soil erosion;
  = less infiltration reduces the growth of the grassland vegetation;
  = large temporal fluctuations of rainfall affects plant productivity : the areal biomass production varies from one year to the other;
  = less areal biomass increases susceptibility to surface erosion by either water or wind;

* vegetation cover characteristics modify the available energy Rn-G :
  = limiting soil moisture affectes the vegetation growth inducing higher surface temperatures and soil heat flux;
  = the partitioning of the available energy affects the atmospheric characteristics : less sensible heat decreases the air temperature Ta and more evaporation influences the air humidity. These two factors lead to the reduction of the climatic demand. The feedback effect of the surface characteristics upon the atmospheric conditions is well demonstrated during the summer periods with the first rains : less sensible heat is exchanged with the atmosphere and the maximum air temperature is reduced by 3-5°C.
  = large day/night soil surface temperature fluctuations are registred at the dry grassland area.

2. Effects of the surface degradation caused by human activities on climate :

* overgrazing modified the plant growth :
  = leaf area grazed during the plant growth reduces the potentiality of dry matter production. This affects the energy balance : soil heat flux G increases and more sensible heat is exchanged with the atmosphere, increasing the air temperature Ta;
  = bare soil becomes dominant over the area : surface crusting is important;
* overgrazing modified the water balance :
  = disruption of the soil surface structure reduces soil water infiltration (more surface runoff and soil erosion), affecting the soil moisture storage;
  = the evaporation rate is reduced and the total amount evaporated by the dry grassland surface is less than the total amount received through rainfalls;
* less organic matter on the surface >> termites population decreased and soil structural stability declines.

The diverses processes of grassland degradation are not all active at the same time and in the same place.

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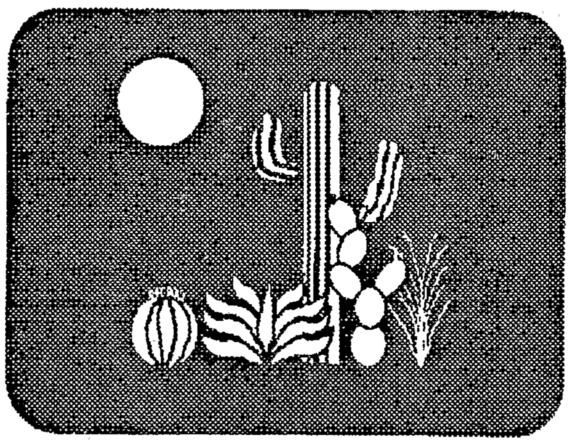
UNIVERSIDAD DE SONORA

Memorias

SYMPOSIUM INTERNACIONAL SOBRE LA UTILIZACION Y APROVECHAMIENTO DE LA FLORA SILVESTRE DE ZONAS ARIDAS



Academia de Recursos Naturales Terrestres del Departamento de InvestigacionesCientíficas y Tecnológicas de la Universidad de Sonora

Del 4 al 6 de marzo de 1998
en Hermosillo, Sonora, México.

Lugar Sede
Centro de las Artes de la
Universidad de Sonora