ELSEVIER

Agriculture, Ecosystems and Environment 55 (1995) 7–16

Agriculture Ecosystems & Environment

Climate variability and agroecological change in the Central Pampas of Argentina

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Accepted 3 May 1995

Abstract

Global warming is likely to alter natural and agricultural ecosystems, probably causing relocation of some of the major crop-producing regions, and a change in the geographic distribution of rangelands and forests. More important than the direct effect of the temperature increase, would be any alteration in the rainfall pattern in those many regions where rainfall limits crop production. The purpose of this work, which focuses on a traditional, semi-arid, cattle–cereal crop production area in the Central Pampas of Argentina, was to study structural and functional changes in this agroecosystem in response to the measured climate variability over a 30 year period, 1960–1990. Using long-term data, correlation analysis was used to estimate the degree of association between changes in the land use pattern on the one hand, and changes in rainfall, grain price and crop yield on the other hand. Crop yield was the result of an interaction between climatic and technological factors. The analysis also linked climate variability with key agroecological factors such as hydrology, energy flow, and soil nitrogen balance. The results showed that changes in land use were highly correlated with the yield of crops, less correlated with rainfall, and poorly associated with crop grain prices. A positive correlation between the annual rainfall and the relative increase of the crop area was found for all districts analyzed. This change could largely explain the increased energy flow as well as nitrogen loss in the agroecosystem studied. Consequently, land use strategies should be considered with caution, especially during favorable climatic period in semi-arid environments. The same conditions that favor grain harvesting in these environments, may also set at risk the sustainability of a long-term, low-input agriculture.

Keywords: Climate change; Land use patterns; Agroecological change; Argentine Pampas

1. Introduction

What kind of agroecological change would be expected in response to the global climate changes predicted? Little can be known with any certainty how different regions, agroecosystems, crops, livestock and natural communities would be affected by a shift in the atmospheric conditions. Some authors such as Mitchell (1985) and Jaeger (1988) believe that global warming could alter the location of the main food-producing regions, especially in the higher mediterranean latitudes, whereas in the arid and semiarid areas, agriculture would expand. At high latitudes agriculture could benefit in areas where temperature now limits primary production. The distribution of forests and rangelands could also change. If other climatic variables remain unchanged, higher temperatures would probably reduce the extent of the world forests (Emanuel et al., 1985), because seedlings are vulnerable to warming and forests would be affected simply because of the

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SSDI 0167-8809(95)00608-7

lack of regeneration in their current locations (Davis, 1986). In a warmer climate, an expansion of grassland, savannas and desert areas has been predicted (Crosson and Rosenberg, 1989), increasing the vulnerability of such areas to erosion and fire. Rangelands may undergo a shift in community composition to species which tolerate water stress and compete strongly for nutrients (United States Department of Energy, 1985). The more successful species will not necessarily be the most suited for forage and grazing.

Higher concentrations of CO_2 in the atmosphere will change the growth of plants by increasing the rate of photosynthesis, especially in crops that have a C_3 – carbon pathway such as wheat, barley, rice, potatoes, etc. (Cure, 1985; Warrick et al., 1986). Increased CO_2 would also have some negative effects: the food quality of plants may decline, leaves becoming richer in carbon and poorer in nitrogen, with insect pests consuming more to compensate the lower nitrogen levels (Oechel and Strain, 1985).

Changes in rainfall patterns are more uncertain. Hydrological processes are not well predicted by General Circulation Models (GCM) as yet: a poor regional match between GCM simulated results and observations is observed, limiting their usefulness under different land use scenarios. At a regional level, alteration in rainfall patterns are likely to have a greater ecological and socio-economic impact than the direct effect of small increases in the annual mean temperature (International Geosphere-Biosphere Programme, 1992). Changes in precipitation are specially important in regions where the lack of rainfall is a limiting factor for crop production (Parry, 1990).

Focusing on the subhumid area of the central pampas of Argentina, the objective of this study was to assess some basic relationships between the climate variability and the corresponding agroecosystem response during the 30 year period of 1960–1990. This study was conducted under the following two assumptions: (a) major changes in structure and function of the agroecosystems were related to changes in the climate, and (b) variations in the climate conditions can explain a large part of the variability observed in the land use, the hydrological process, the energy flow, and the nitrogen (N) cycle, exceeding the influence of economic and technological factors.

2. Materials and methods

The study area, approximately 5.0 million ha, which covers the Eastern districts of La Pampa province, is part of a 20 million ha semiarid plain, located on the Western part of the central pampas in Argentina. Cattle production is the main activity in the region, where annual and perennial forage species rotate periodically with crops like wheat, maize, sorghum and sunflower. Historically, the region was considered as limited by the 500 mm annual rainfall isohyet on the West, and the 700 mm one in the East (Hall et al., 1992). However, a recent work of Roberto et al. (1994) shows considerable displacement of isohyets toward the West during the last 30 years (Fig. 1). This increase in annual rainfalls was accompanied by a change in the seasonal pattern of spring and summer precipitations (Roberto et al., 1994).

The following sources of data were used for the analysis: (a) long-term climatic records obtained from the Instituto Nacional de Tecnologia Agropecuaria (INTA), and the Servicio Meteorologico Nacional (SMN), (b) statistical data of crops (area and yield) collected from the 12 Eastern districts of La Pampa, (c) historical data of cattle production collected from farms grouped in the Consorcios Regionales de Experimentacion Agricola (CREA organization), and (d) energy and nitrogen (N) concentration and inputs, and average uptake values as determined by various authors.

Annual values of rainfall (mm), temperature (°C), and global radiation (GJ m^{-2}), were the main variables analyzed. Correlation analysis were used to estimate the degree of association between climatic and production variables. Agroecological modifications were described by changes of structure and function in the ecosystem. Thus, changes in land use patterns on the one hand, and in the hydrological process, the energy flow and the nitrogen cycle on the other hand, were analyzed during the 30 year period (1960–1990).

Land use patterns were assessed by analysing changes in the relative area devoted to crop and cattle production. Land use changes were compared with rainfall, price of products, and technological levels attained (annual production per hectare) in order to determine which factors explained more the variability in land use. Because prices and production levels of different crops are not comparable, relative indices

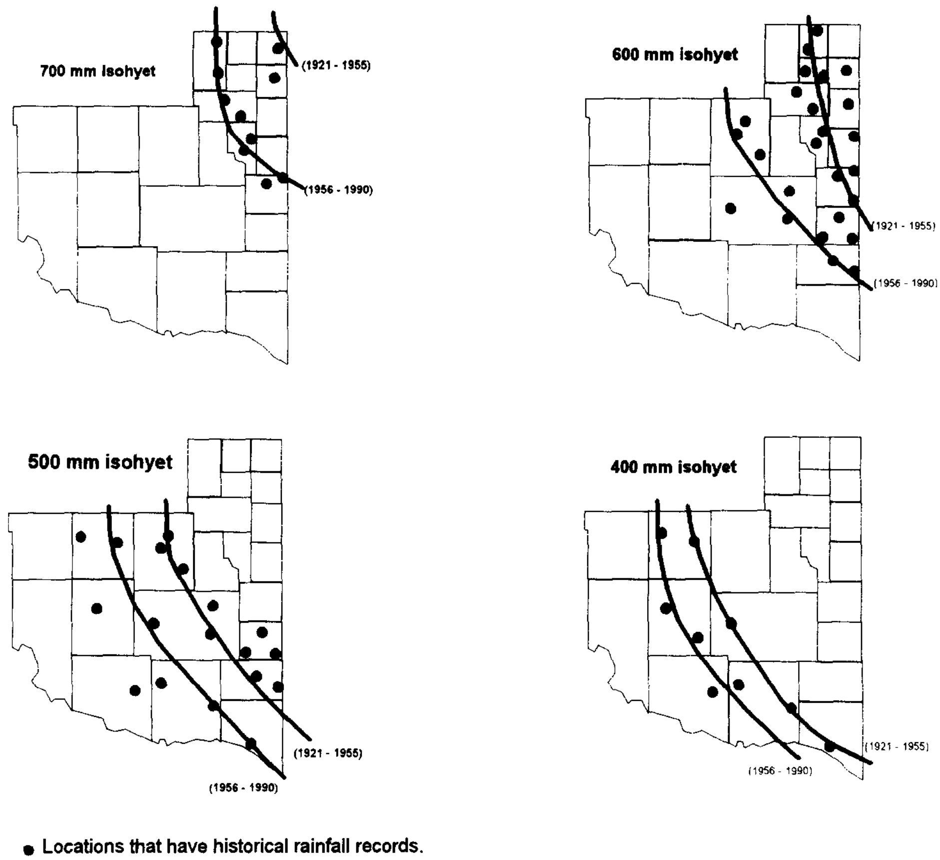

Fig. 1. Western displacement of isohyets in La Pampa province during 35 years.

were utilized for statistical analysis. Variations in the hydrological process were studied by the estimation of the hydrological balance at one representative location (Anguil) using the Thornthwaite (Thornthwaite and Mather, 1955) method. The method estimates balances by using rainfall records and potential evapotranspiration figures calculated from standard meteorological data, and adjusted for different plant and water soil conditions. Changes in energy flow were analyzed by using an energy model (Odum, 1975) considering some basic input–output relationships. Both, inputs and outputs, were converted into energy units (MJ) per unit land area (hectare). According to estimations of Reed et al. (1986), the annual energy application of different inputs (in MJ ha^{-1}) that was adopted for the entire study area were 277 for machinery, 2126 for fuels, 203 for seeds, 175 for insecticides and herbicides, 12 for input transportation averaging 32 km, and 639 for product transportation (also 32 km). The adopted average energy values were 25.53, 16.33 and 13.36 MJ per kilogram respectively for sunflower seed, other seeds, and for bovine meat.

Nitrogen (N) was the only element considered in this analysis because it appears to be the main limiting nutrient to crop production at a regional level (Darwich, 1991). A simple nitrogen balance was estimated with two main sources of gain and loss. N extraction from soil by crops and cattle production was subtracted from hypothetical N gain added to the soil by legumes. At a regional level, the 30 years estimates were based on the following variables: the area devoted to crop production, the area devoted to legume perennial pastures, the N lost in outputs (grain and beef), and the N gained from the atmosphere by fixation of leguminous pastures. As no reliable values of N incorporation were available, the analysis considered five hypothetical rates (50, 75, 100, 125 and 150 kg N ha^{-1} $year^{-1}$) that would be possible under semiarid conditions

Table 1
Correlation analysis to study the behavior of different climatic variables over a period of time

Climatic variables (annual values)	Mean values	*a*	*b*	*r*	SE	*n*
Mean temperature (°C)	15.1	−13.1	0.014	0.253[a]	0.47	29
Maximum average temperature (°C)	22.7	17.8	0.002	0.030[a]	0.69	29
Minimum average temperature (°C)	7.3	−54.1	0.031	0.451[b]	0.53	29
Average soil temperature (°C)	17.1	48.6	−0.020	−0.100[a]	0.91	19
Rainfall (mm)	645.2	−5709.0	3.250	0.387[c]	163.10	72
Global radiation (MJ m^2)	18.86	344.3	−0.164	−0.569[b]	1.38	19

[a]$P > 0.05$, [b]$P < 0.05$, [c]$P < 0.01$.
Analysed periods were: 1921–1992 for rainfall, 1964–1992 for air temperature and 1972–1990 for soil temperature and global radiation. Data were recorded at the location of Anguil.

according to the literature. N losses were closely related to the nature of products (yield and N concentration) and the relative area devoted to them. Average values of N concentration (grams N per kilogram of product) were 22.88 for wheat, 19.84 for sorghum, 16.00 for maize, 60.80 for sunflower, and 25.60 for beef (Lloyd et al., 1978). Values are not expressed on dry matter basis.

3. Results and discussion

The lack of long-term climatic and agroecological data is the main constraint to this type of study. In spite of the fact that the agricultural history of the study region began at the end of the 19th century, it is only recently, i.e. from 1960, that farmers and agricultural organizations have begun to collect data systematically. A few locations have a complete set of rainfall records available from the beginning of this century, but this is not the case for other relevant climatic variables, such as temperature, air humidity, solar radiation, cloudiness, and wind.

3.1. Climate variation

Over the last three decades, the regional climate change can be summarized as increases in temperature and precipitation and a decrease in global radiation (Table 1). With respect to rainfall, a number of locations have long-term records of more than 70 years, but data for temperature, radiation and other meteorological variables were only available from the beginning of the 1960 decade, and were not available for all locations. Because of these constraints, it is difficult to determine if these changes represent a trend or simply statistical noise, and climate variation appears a more appropriate term than non-reversible climate change.

3.2. Climate and land use change

Significant shifts in the regional pattern of land use took place during the last three decades in the area considered. The average area devoted to cattle production decreased persistently and the crop production area increased fourfold in the same period (Fig. 2a). However, the increases were not the same for all crops. The summer crop area increased more than the areas of winter crops and perennial legumes. The latter appears rather stable (Fig. 2b). The relative substitution of pastures and some annual crops by other crop species, was the major change in the regional agroecosystem. Structural, biological and technological factors have affected the overall agricultural process, disturbing two key ecological functions: the energy flow and the nitrogen cycle.

A simple correlation analysis was done to study the degree of association between changes in the crop production area, and three external variables which represent (1) the climate (rainfall), (2) the economic condition (price of grains), and (3) the technological advances (crop yields). In order to incorporate all grains and crops, prices and yields were estimated using a yearly average relative value (1.0 for the first year) for all grains and crops. As Table 2 shows, correlations were positive for all districts and variables, but their statistical significance varied greatly among districts and variables. The degree of correlation with land use change appears to be relatively high for crop yields,

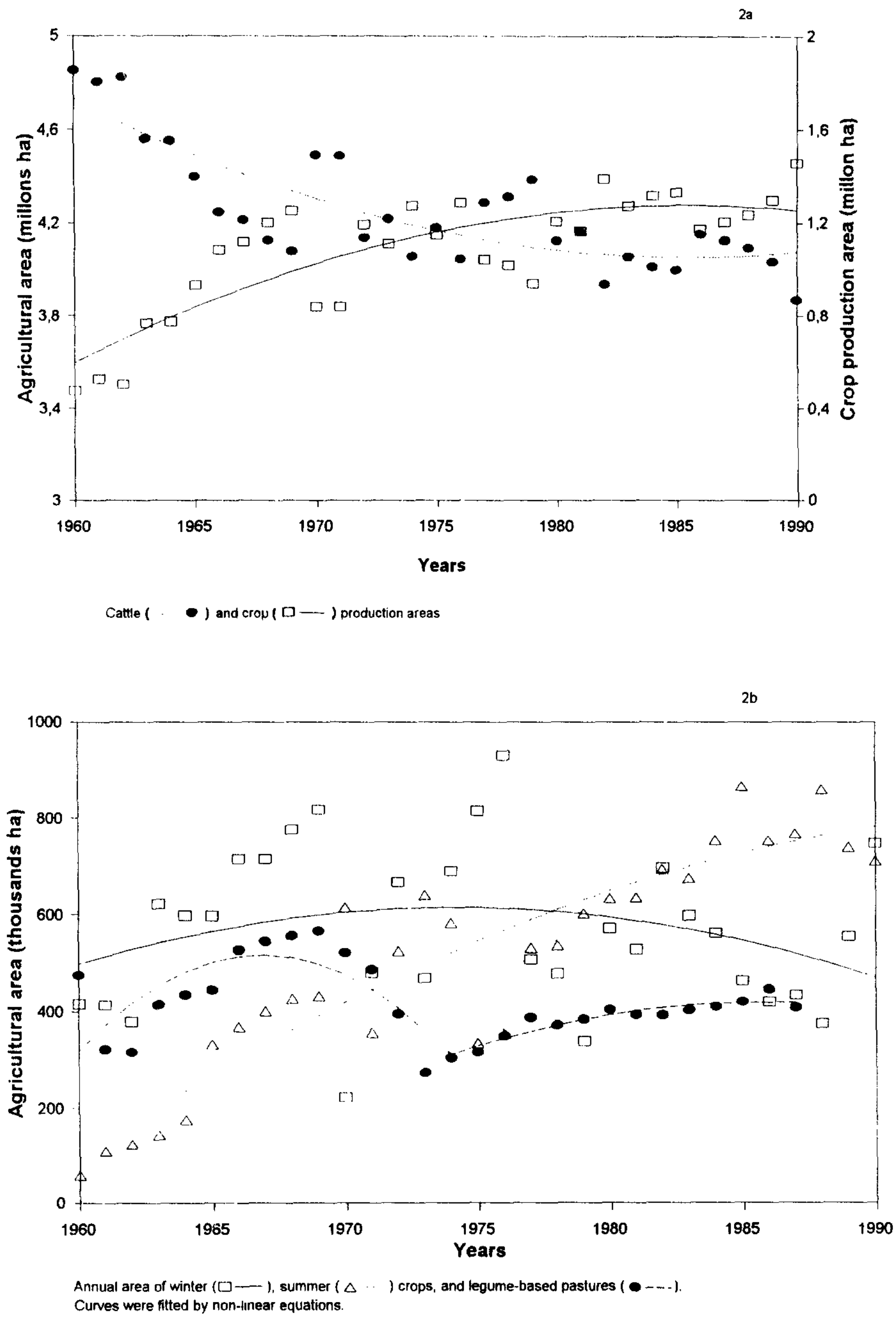

Fig. 2. Changes in the regional land use pattern during three decades (1960-1990).

moderate for rainfall, and low for grain prices. Multiple correlation analysis did not improve the simple relation obtained for crop production area and crop yield.

A relevant question, not answered here, is what amount of the crop yield variability would be attributed to the improved climate conditions, and what amount to technological factors such as inputs and management practices. It is probable that rainfall had a direct effect on land use as well as an indirect effect through the

Table 2
Simple correlation analysis for estimating the degree of association between the crop production area arid and three external variables, rainfalls, grain prices, and crop yields

Name of the study districts	Rainfalls		Grain prices		Crop yields	
	r	SE	*r*	SE	*r*	SE
Atreuco	0.57[c]	6.71	0.30[a]	7.83	0.78[c]	5.09
Capital	0.26[a]	6.06	0.31[a]	7.92	0.69[c]	6.05
Catrilo	0.60[c]	7.80	0.32[a]	9.27	0.80[c]	5.92
Chapaleufu	0.26[a]	8.94	0.30[a]	8.83	0.73[c]	6.33
Conhelo	0.25[a]	11.31	0.13[a]	11.56	0.41[b]	10.65
Maraco	0.48[c]	7.89	0.31[a]	8.53	0.70[c]	6.38
Quemu-Quemu	0.27[a]	9.12	0.22[a]	9.24	0.64[c]	7.27
Rancul	0.58[c]	5.12	0.54[c]	5.27	0.79[c]	3.84
Realico	0.55[c]	8.02	0.17[a]	9.43	0.55[c]	7.99
Toay	0.32[a]	5.35	0.16[a]	5.57	0.61[c]	4.46
Trenel	0.18[a]	9.27	0.21[a]	9.20	0.46[c]	8.37

$n=29$.
[a]$P>0.05$, [b]$P<0.05$, [c]$P<0.01$.
Correlations for grain prices and crop yields were estimates from the average relative values for all grains and crops. Analysed period: 1962–1990.

crop yield increase, thus having an overall impact greater than that indicated.

3.3. The climate and the hydrological process

The hydrology of the region was analyzed using data on the rainfall regime, the hydrological balance, and changes in the water table over the study period. This analysis helps to explain the behavior of agroecosystems under conditions of increasing moisture supply.

Long-term rainfall patterns in Pico and Anguil show a non-linear behaviour (Fig. 3). An overall trend with a sharp increase in the last 30 years after a dry period during the previous 30 years is noted. In relative terms, soil water content increased more than water losses by evapotranspiration as it was estimated by the Thornthwaite (Thornthwaite and Mather, 1955) method. According to this method, evapotranspiration is calculated from a complex function of temperature. As a consequence, the evidence shows that the negative hydrological balance in Anguil tends to become less evident (Fig. 4). However, the water table level rises over time, approaching the ground surface and increasing the risk of floods, mainly during the spring and summer periods.

The increase of the area of crops at the expense of the grazing areas would not have been possible, in such a semiarid environment, without an overall improvement of hydrological conditions.

3.4. Climate and the energy flow

Increases in the crop area and the crop yield in response to better environmental conditions have changed the ecosystem energetics on a regional scale. These changes can be detected by analysing changes

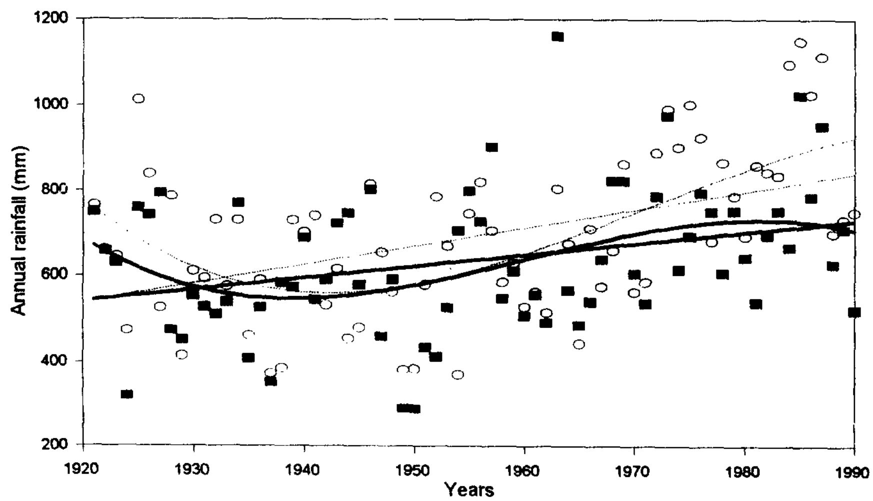

Fig. 3. Linear and cyclical patterns of rainfall at the locations of General Pico (O—O) and Anguil (■—■) over a period of 70 years, fitted by linear and cubic equations.

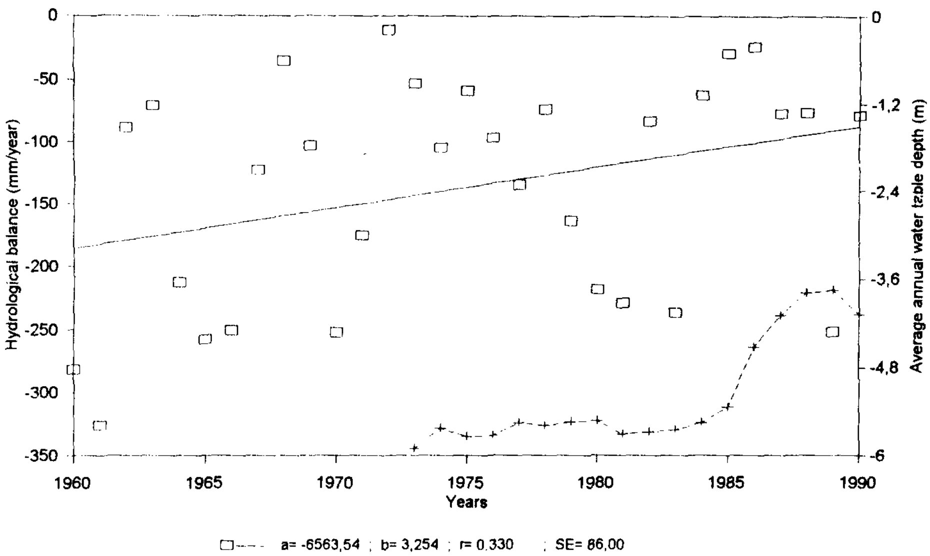

Fig. 4. Evolution of the hydrological balance (□) and the water table level (+—+) at the location of Anguil.

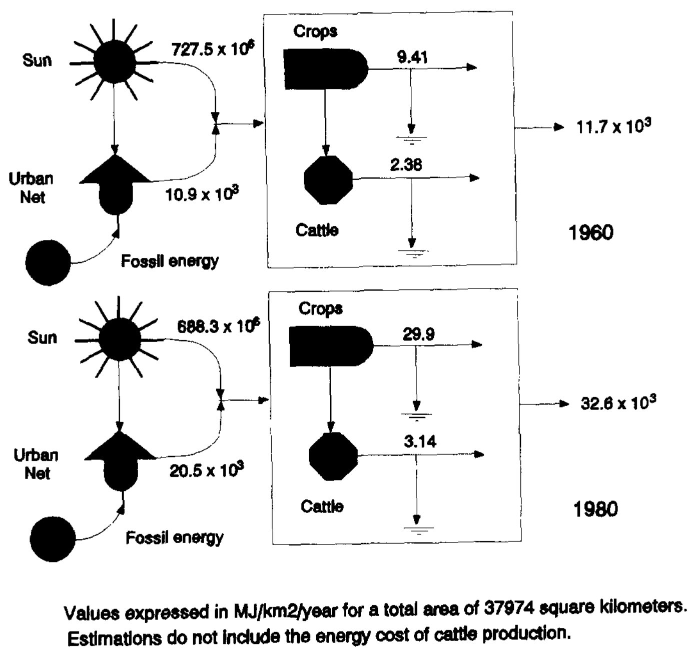

Fig. 5. Estimated global energy flow for agricultural processes in the study region under different historical scenarios.

in the energy input–output relationships, as well as in the rates of energy transfer within the overall ecosystem's energy flow (Odum, 1975). Fig. 5 shows some of these modifications in the energetics of the regional agroecosystem estimated for the decades of the 1960s and the 1980s. During this period the ecosystem moved

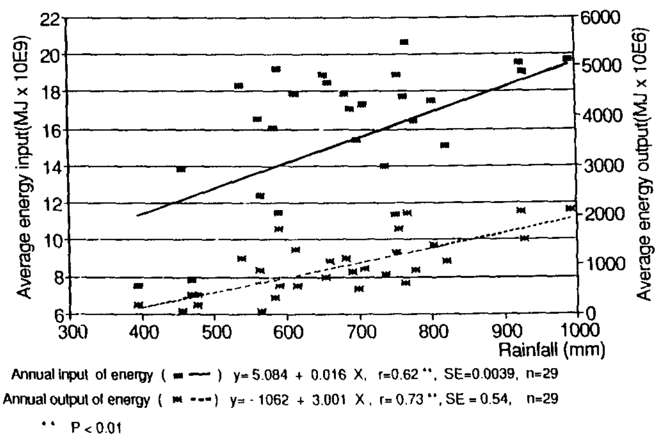

Fig. 6. Relationships between annual rainfall and the annual energy flux in agriculture for the study region during the period 1960-1990.

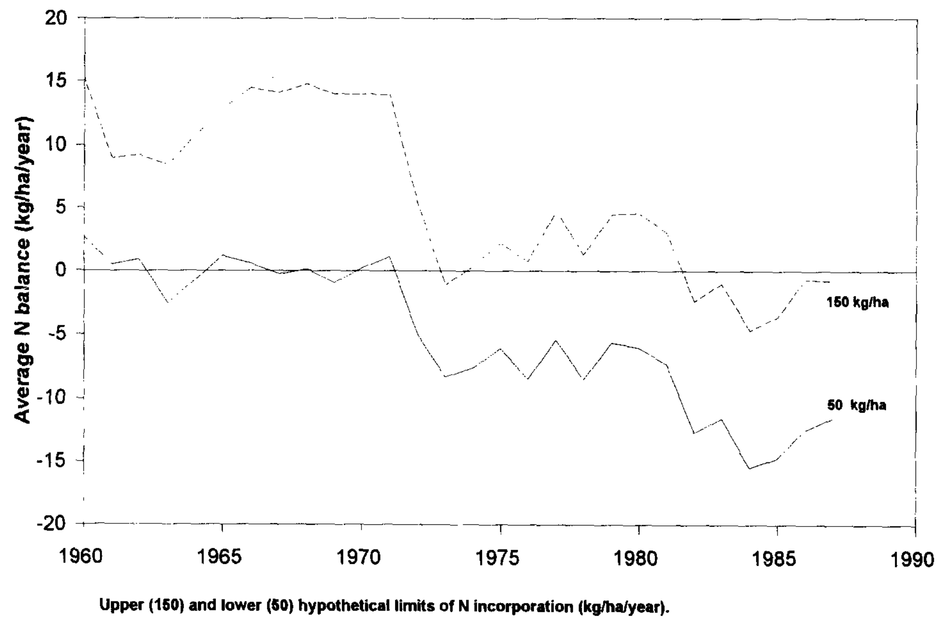

Fig. 7. Estimated trends of the annual N balance in soils during three decades assuming five hypothetical rates (50, 75, 100, 125 and 150 kg ha^{-1} $year^{-1}$) of N incorporated by legumes.

from its natural condition, which was strongly dependant on solar energy.

Estimations of fossil energy inputs as well as grain and beef energy outputs, appear correlated to annual rainfall (Fig. 6). At a regional level, estimates suggest an increase of 1.60 millions GJ in the annual input of fossil energy was associated with each 100 mm increase in rainfall. However, an output increase of 0.36 millions GJ of grain and beef was associated with each 100 mm increase in annual rainfall. According to the above, the regional energy budget, in response to better hydrological conditions, has shifted the ecosystem towards a higher energy status. However, efficiency in terms of energy input–output decreased as rainfall increased.

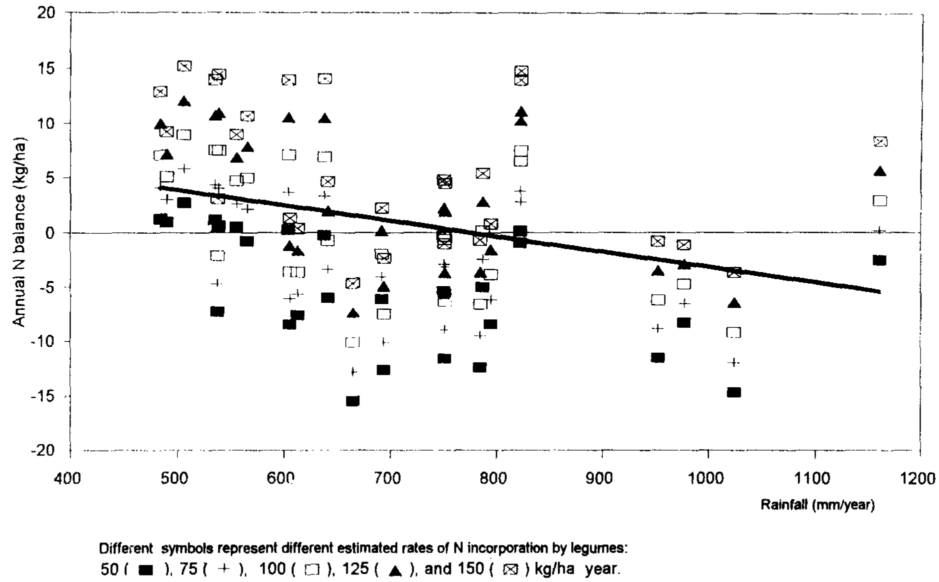

Fig. 8. Correlation between rainfall and the estimated range of annual oil N balance, assuming five hypothetical rates of N incorporation by legumes.

3.5. Climate and nitrogen balance

Whatever the rate of N incorporation selected, the estimated N balances consistently showed an ecosystem in net loss (Fig. 7). The decline in the N status of the system during the last three decades, coincided with the fact that while the crop area increased, the area with perennial legume pastures remained constant (Fig. 2b). A negative correlation ($r = -0.36$, $P < 0.01$, $SE = 6.63$, $n = 150$) was obtained between rainfall and N balance (Fig. 8). In spite of the low correlation, this negative relationship is consistent with the increasing imbalance of areas devoted to annual crops and perennial legumes pastures during the three decades, and the increasing rainfall in the same period.

4. Conclusions

The results of this study show that changes in land use in the region were highly correlated to the yield of the crops, less correlated to the rainfall pattern, and poorly associated with the crop grain prices. However, as crop yield is the product of an interaction between the climate and the technological factors, the climate having a direct as well as an indirect effect on land use change, produced an overall effect greater than that specifically assessed, although the importance of the respective effects could not be determined in statistical terms. It is noticeable that a key economic factor such as the grain prices was poorly related to changes in the annual crops area. In principle, this means that farmers tended to respond more to improvements in climate and technological conditions, and less to changes in the price of their crop products.

The above attempts to predict agroecological changes as a response to climate variation should be viewed cautiously at this stage. However, and in spite of the constraints imposed by the short three decade period, we found no evidence in our results which refute the hypothesis of a link between climate and agroecological change. Structural changes in land use as well as functional changes in the hydrological process, the flow of energy and the N cycle, would in part be associated with changes in climatic variables during the last 30 years. Nevertheless, another major part of agroecological variability could be related to variations in other non-climatic variables. The importance of the economic, the socio-political and the technological ones cannot be disregarded, and deserves careful study.

Considering the natural limitations of all semi-arid environments, caution is called for regarding the general response of regional farmers to expand the crop area assuming that the beneficial climatic changes will continue. The potentially negative effects of cash crop expansion in vulnerable environments leaves little room for complacency. The same climatic conditions that favor crop production, do not favour a sustainable long-term agriculture as the results of this study demonstrate. As rainfall and cash-crop area increased, the ecosystem was moved to a higher and fossil fuel based energy budget, which in turn determined higher levels of N mobilization and extraction. A deterioration in the physical and chemical properties of the soil can be expected as a consequence.

Although research is still needed to confirm current climatic trends and their potential effect on ecology and agriculture, the generalised impact that this short-term climate change appears to have on the regional food-chain cannot be ignored. Alternative approaches for land use and technology adaptations are needed to face probable scenarios of change in climatic conditions in the near future.

Acknowledgements

The authors acknowledge the technical assistance provided by Guillermo Casagrande, climatologist of Anguil Experimental Station (INTA). The fruitful comments of the reviewers were also very useful.

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