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## Drought in the Sahara: Insufficient Biogeophysical Feedback?

In a recent report (*1*) Charney *et al.* used a global general circulation model to test the hypothesis that overgrazing in the Sahelian zone might be, at least in part, responsible for the recent drought in that region. They claimed that their results supported this hypothesis.

A major criticism of their work is that, although they have taken account of the vegetation's effect on albedo, they have completely ignored its effect on evapotranspiration. Even though vegetated surfaces often absorb more radiation than bare ground, they are usually cooler because much of the absorbed energy is used to evaporate water. It is also regrettable that Charney *et al.* continue to subscribe to the idea that localized land and vegetation management can have a significant effect on rainfall climate.

In view of the scarcity of published data on Saharan albedo, the value of 0.35 used by Charney *et al.* does not appear to be unrealistic (*2*). The albedo postulated for a vegetated Sahara (0.14) also appears to be reasonable (*3*). However, this could vary considerably with type of vegetation, ground cover, and moisture status. Although it is true that a decrease in the albedo of a surface will cause an increase in the net radiation income, for a decrease effected by adding live vegetation one must expect that at least part of the extra energy will be used in transpiration. The addition of water to the atmosphere, through transpiration, probably would not enhance precipitation since atmospheric moisture is already quite high (*4*) and the effect of a slight augmentation is not likely to be great (*5*).

If the albedo change is effected through the use of vegetation, as implied in Charney *et al.*, transpiration will be a necessary consideration and a change in the surface energy budget can be expected. Van Bavel and Fritschen (*6*) compared energy balances over dry and wet soils and found that, although the daily net radiation was about 20 percent greater over the wet soil, the sensible heat flux to the atmosphere and the surface temperature were both greater for the dry soil. I carried out a comparison of two adjacent areas in a natural savanna region of northeastern Uganda (*7*); one area was heavily grazed, and the other was protected from grazing (Table 1). These data show the grazed surface, in spite of its higher albedo and lower net radiation, to be considerably warmer during the daytime than the ungrazed surface. Thus, protection from overgrazing might be expected to reduce convection and precipitation rather than to increase them.

If the Saharan albedo change could be effected by artificial means, so as to avoid transpiration, then the results of Charney *et al.* would likely apply. This case also deserves comment. Figure 2 of Charney *et al.* shows an increase in rainfall to the north of 16°N for the lower albedo case but a decrease south of this latitude. Examination of a population distribution map (*8*) shows that there is a very low population density between 16°N and 25°N compared with the very high density between the equator and 16°N. In addition, an article in the *World Meteorological Organization Bulletin* (*4*) describes the Sudano-Sahelian zone as lying "approximately between latitudes 10°N and 20°N." Thus, even without transpiration, the effect of decreased albedo appears to be a reduction of rainfall in the most heavily populated region of the Sahel.

The presentation of the results in Charney *et al.* also invites criticism. The choice of the month of July and the use of latitudinal averages obscure pertinent spatial and temporal variations. Although the precipitation pattern depends most strongly on latitude, there is some variation with longitude, particularly south of 10°N (*8*). Whereas the summer months are the wettest in the latitudes 10°N to 15°N, farther north autumn and winter are the rainiest seasons (*9*). Therefore, one must not assume that the effect on annual precipitation would be the same as that simulated for the July precipitation, particularly in the more northerly part of the zone.

As a final point, the July rainfall values indicated by Charney *et al.* (in their figure 2) for the region north of 15°N appear to be far higher than those reported elsewhere (*10*).


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28 February 1975


Ripley's criticisms are apposite. We are grateful for the opportunity they provide to clarify the physics of our model and to discuss further the implications and limitations of our results. His major criticism is that, while considering the effect of changes in vegetative cover on albedo, we have completely ignored the effect of vegetation on evapotranspiration. He points out that vegetated surfaces are usually cooler than bare ground because much of the absorbed solar energy is used to evaporate water, and he concludes from this that protection from overgrazing might be expected to lower surface temperatures and thereby reduce rather than increase convection and precipitation. We agree with his premises but not with his conclusions. It is true that the very primitive hydrology

Table 1. Mean daily energy balance data for 4 days (0700 to 1900, local time) for a savanna area in northeastern Uganda in January 1964 (*5*). The effective surface temperature values were obtained from radiation measurements, assuming an emissivity of 1.0.

| Area | Global radiation (joule $cm^{-2}$) | Net radiation (joule $cm^{-2}$) | Albedo | Effective surface temperature (°C) |
|---|---|---|---|---|
| Grazed savanna | 2340 | 1256 | 0.20 | 34.7° |
| Ungrazed savanna | 2340 | 1549 | 0.15 | 29.2° |

of our model did not specifically provide for the effect of plants on evaporation, and consequently that the relative evaporation rates were probably underestimated and the surface temperatures were overestimated in the presence of vegetation. But we do not agree that convective rainfall simply increases with the temperature of the ground. The essential point is that the *total* energy imparted to the atmosphere (sensible plus latent heat) is *increased* in the lower layers when the albedo is decreased. The important quantity determining convective precipitation is the negative vertical gradient of moist static energy, $c_pT + Lq + gz$ (where $c_p$ is the specific heat at constant pressure, $T$ is the absolute temperature, $L$ is the specific latent heat of evaporation, $q$ is the specific humidity, $g$ is the acceleration of gravity, and $z$ is the height), and this negative gradient is increased when the albedo is decreased. Simply said, if additional solar radiation goes into $Lq$ rather than into $c_pT$, it is very soon converted to $c_pT$ by convective precipitation. Ripley's contention that the increased moisture would probably not enhance precipitation anyway would be correct if the air were stable for a saturated-adiabatic process, or if it were so dry that the falling precipitation would reevaporate before it reached the ground, or if both conditions obtained, but it cannot easily be decided on a priori qualitative grounds whether or not such will be the case. It was not so in our model, where the air in the lower troposphere was moist convectively unstable and the clouds were deep enough to prevent reevaporation.

We have since carried out additional integrations, and these appear to confirm our preliminary results which led to the conclusion that an increase of albedo in the Sahel alone would produce an appreciable decrease of precipitation there. Even when there is no evapotranspiration, the precipitation is somewhat decreased because the increased albedo reduces the northward reach of the moist monsoon air from the Atlantic. These results are shown in Figs. 1 and 2, which compare the longitudinally averaged changes in rainfall in July over Africa produced by a change of albedo in the Sahel strip from 14 to 35 percent. Figure 1 shows the latitudinal distribution of rainfall calculated from our earlier model in which the ground wetness at each point was kept fixed at its climatological value. In this model the evapotranspiration of the semiarid zone was found to be excessive. For want of a satisfactory treatment of the hydrology, we decided to bracket the results by carrying out a computation with essentially no evapotranspiration at all. These results are shown in Fig. 2, but in this case their statistical significance is more open to doubt, as may be seen from Fig. 3 which presents a comparison of the changes in Sahel rainfall week by week for each of the two cases.

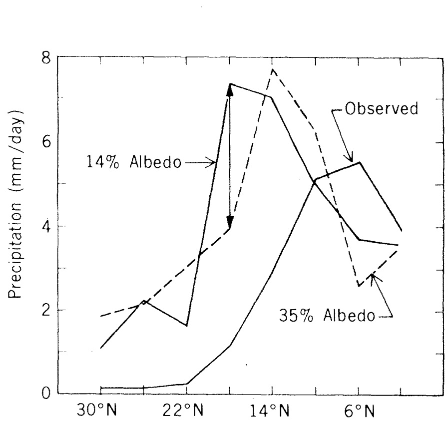

Fig. 1. Latitudinal distribution of zonally averaged mean rainfall during July in North Africa for the case of fixed ground wetness and excessive evaporation.

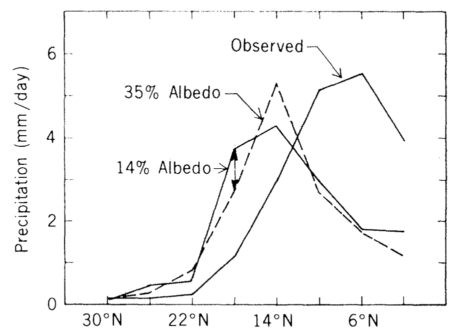

Fig. 2. Latitudinal distribution of zonally averaged mean rainfall during July in North Africa for the case of variable ground wetness and negligible evaporation.

In the present state of our knowledge, we can take no strong exception to Ripley's other comments and criticisms. Our results do indicate a decrease of rainfall immediately south of the latitude at which an increase of vegetation causes an increase of rainfall, and this finding is in agreement with the observation that the recent drought in the Sahel was accompanied by increased rainfall just to the south (*1*). We admit the justice of his criticism that longitudinal averages for a single summer month obscure pertinent spatial and temporal variations. We can only say that space limitations in *Science* prevented our presenting more than two diagrams and that we do intend to publish the two-dimensional distributions elsewhere (*2*). But we do not admit that July is not representative of the annual average for the sub-Saharan regions north of 15°N or that the wettest season is in the autumn and winter. We find no evidence for this in Ripley's own reference to African climatology (*3*) or in Thompson's climatological atlas (*4*) which gives more detailed rainfall data. The months of greatest rainfall north of 15°N are June through September with a maximum in August. There is no rainfall to speak of north of 15°N in winter.

Finally, it is true that our calculated rainfall values north of 15°N were higher than those reported elsewhere. We believe this to be due in part to insufficiently representative albedos, in part to the excessive evapotranspiration in the semiarid regions included in the model, and in part to deficiencies in the treatment of cumulus convection in the model. With no evapotranspiration at all, the values correspond better with reality.

We apologize if we have unintentionally conveyed the impression that ours was more than a preliminary study of the impact of a hypothetical change of albedo on rainfall, but we have as yet found no evidence to lead us to think that the effects are not genuine. We continue to believe that they can occur in the wet season in all areas where the precipitation is largely convective and for which the radiative or convective time constants, or both, are not greater than the relevant advective time constants. Since such areas cover a large part of the globe, there appears to be some urgency to measuring and documenting ac-

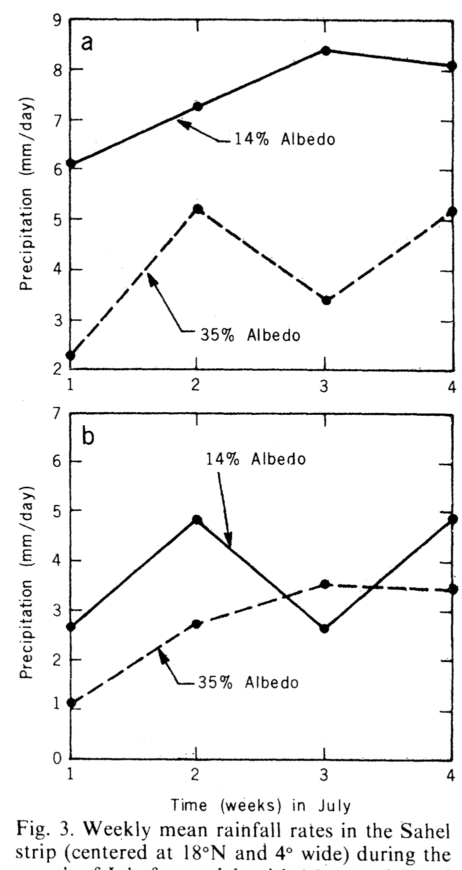

Fig. 3. Weekly mean rainfall rates in the Sahel strip (centered at 18°N and 4° wide) during the month of July for models with (a) excessive and (b) negligible evaporation.

tual albedo changes and to carrying out further numerical simulations with improved mathematical models until more definite conclusions can be obtained and acted upon.

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5. The new work reported here was done with the collaboration of Drs. J. Kornfield and S. Chow. We are very much indebted to them for their help.

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## Pleistocene Extinctions

Long and Martin (*1*) present various radiocarbon dates of *Nothrotheriops*, an extinct ground sloth. As Martin (*2*) claims that his Pleistocene explosive overkill hypothesis is essentially untestable except for the radiocarbon chronology, it is important that the latest dates for existence of extinct forms proceed from North to South America. The dates presented do not exhibit this pattern even though Long and Martin claim they do. In fact, the two latest dates presented come from North America. Long and Martin claim that there was a constant rate of dung deposition with no decline in deposition rate toward the top of the deposit "as might be expected if the population were coming under stress gradually," and use this relationship to support the overkill hypothesis. An annual deposition rate of "perhaps less than a week's elimination of one adult sloth" is so small as to tell us absolutely nothing about the total population fluctuations.

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Our purpose was to replicate, if we could, the radiocarbon dates on which Martin, Sabels, and Shutler based their conclusion that the Shasta ground sloth was alive at least until 10,000 years ago (*1*). Our new suite of samples yielded none from North America much younger than 11,000 years in age (*2*). Pending new discoveries or a successful replication of L-473A, Y-1163A, or C-222 we conclude that Shasta ground sloth extinction was remarkably close in time to the arrival of the first big game hunters in North America, and slightly before sloth extinction in South America.

We agree that the rate of dung deposition in Rampart Cave may not reflect population dynamics of the extinct sloths. On the other hand, seven North American caves are known to contain sloth dung. Radiocarbon dates obtained since our report was published (*2*) show that all seven were occupied by sloths within a few hundred years of the time when we believe they suddenly disappeared. The result does not suggest a population coming under stress gradually, or one suffering a gradual reduction in its range.

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## Correction in the Glacial-Postglacial Temperature Difference Computed from Amino Acid Racemization

The extent to which L-amino acids racemize to D-amino acids is a function of both time and temperature as well as other environmental conditions (*1*). Assuming mean paleotemperatures and comparable environmental conditions, D/L amino acid ratios have been applied to the dating of fossil bones (*2, 3*), shells (*4*), and sediments (*5–7*).

Conversely, when fossils are datable by other methods, the extent of amino acid racemization has been applied to estimate paleotemperatures (*8, 9*). In particular, Schroeder and Bada (*8*) have estimated the glacial-postglacial temperature difference from amino acid racemization in fossil bones which had been dated by radiocarbon methods. The purpose of this comment is to point out an error in the way the average temperature differences were computed by Schroeder and Bada. Revised calculations result in new temperature differences which lie outside the error limits originally assigned to their method, but which are somewhat closer to the differences estimated by other methods.

Schroeder and Bada use the following model for the past temperature history of the earth

$$T(t) = \begin{cases} T_p & t < 10{,}000 \text{ years} \\ T_p - \Delta T & t > 10{,}000 \text{ years} \end{cases} \quad (1)$$

where $t$ is time in years past and $T_p$ is the present temperature. The difference, $\Delta T$, is the quantity being sought.

Schroeder and Bada inserted measured amino acid ratios and radiocarbon ages into the constant temperature integrated rate law for opposing first-order reactions to determine effective rate constants for two different samples, $\bar{k}_1$ for a sample younger than 10,000 years and $\bar{k}_2$ for a sample older than 10,000 years. The Arrhenius formula was applied to the ratio, $\bar{k}_2/\bar{k}_1$, yielding an effective temperature difference for the two samples. This difference was equated to the time-averaged temperature difference, thus determining $\Delta T$.

Unfortunately, because of this exponential dependence of the rate constant

Table 1. Average rate constants and temperature differences computed from D/L ratios in fossil bones.

| Location | $\bar{k}_1$* ($10^{-5}$ year$^{-1}$) | $t_2$ † (years) | $\bar{k}_2$ ‡ ($10^{-5}$ year$^{-1}$) | $\Delta T$ (°C) | |
|---|---|---|---|---|---|
| | | | | Eq. 6 | Eq. 5 |
| Muleta Cave, Majorca, Spain | 1.72 | 16,850 | 1.25 | 3.9 | 5.6 |
| | 1.72 | 18,980 | 1.22 | 3.7 | 4.8 |
| Lukenya Hill, Kenya | 4.02 | 17,700 | 2.71 | 4.7 | 7.0 |

*A true rate constant for samples of aspartic acid at $T_p$. †Radiocarbon age. ‡A time average rate constant.