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Effects of grazing and trampling on soil deterioration around recently drilled water holes in the Sahelian Zone

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In 1937 Stebbing pointed out that drier climatic conditions were leading to the southward encroachment of the Sahara (*20*). His observations were almost immediately rejected by an Anglo-French commission, which argued that in most cases soil degradation was caused by the action of man (*18*).

Because of the protracted drought of the 1970s in the Sahelian belt, Stebbing's caution recently was brought into sharp focus. According to many scientists, overgrazing and trampling, especially near watering points, are the major causes of soil degradation and, consequently, desertification of this area (*6, 9, 13, 26*). However, published material relating accelerated erosion to animal husbandry remains scarce. Additional information is essential.

Scientific attention has focused on a large region of northern Senegal, which as recently as 30 years ago was called the "Ferlo Desert." At that time, despite the continuous presence of fodder, livestock were herded out of the area as ponds dried up after the rainy season. The Ferlo was thus deserted by nomadic herdsmen 9 months out of each year. Once numerous deep wells were drilled in the 1950s, the seasonal migrations of nomadic communities declined rapidly, and this region was subjected to permanent pastoralism.

Such a radical change in pastoral practices affected many aspects of the human and natural environments. To document such changes, studies recently were carried out in that area. The area provided a large-scale experimental site for an interdisciplinary team composed of investigators of

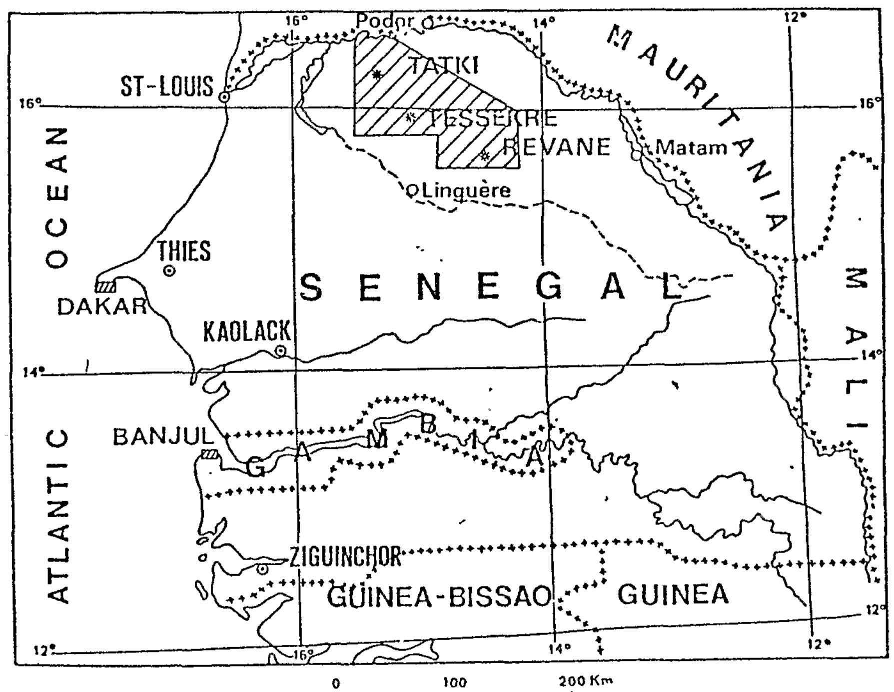
several international, Senegalese, and French institutions, including sociologists, economists, physicians, nutritionists, veterinarians, animal breeders, botanists, and soil scientists.

Here, I present major findings relevant to grazing and trampling around the waterholes on soil deterioration, namely sealing, soil compaction, and wind and water erosion.

Study area

The study area (Figure 1), which covers 10,000 km², sustains a human population estimated at 30,000 and about 100,000 bovine livestock (*16*). The arid rangelands are scattered, with 13 drilled waterholes, 25 km apart. Water is raised from the largest water table in West Africa, the Maestrichtian, which is 200 m deep.

The area has a very hot, dry season that lasts 9 months a year. Rainfall is concentrated between July and September. In this zone data can be misleading because of the wide variability of climatic events. For example, from 1920 to 1969 average annual precipitation ranged from 300 mm



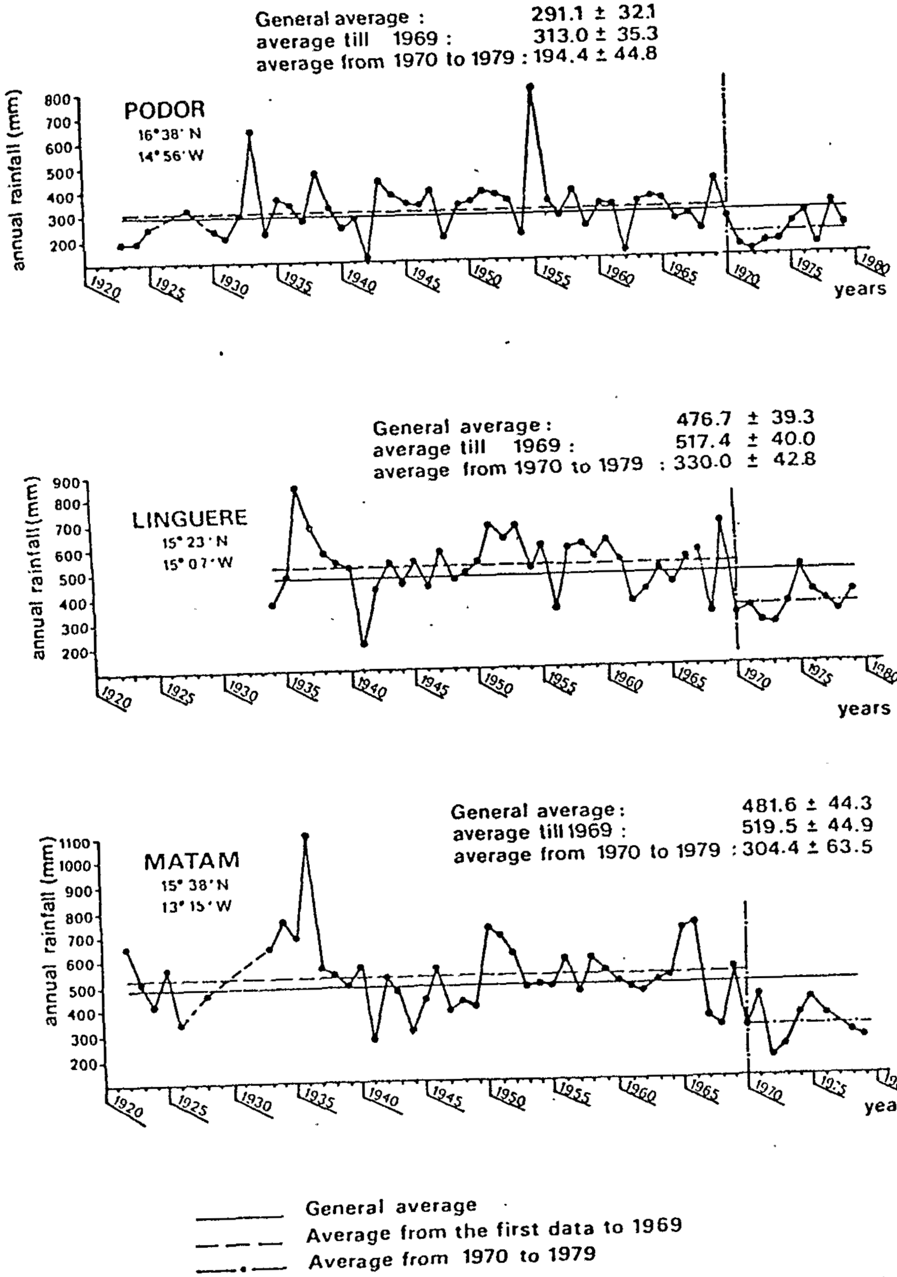


Figure 2. Rainfall and its variability, in three towns bordering the study area (*24*).

in the northern part of the area (Podor) to 500 mm in the southern part (Linguere and Matam). But a general and prolonged rainfall deficit of about 40 percent was recorded throughout the 1970s (Figure 2) (*24*). In 1981 rainfall returned roughly to normal (358 mm in Tatki, 348 mm in Tessekre, and 433 mm in Revane).

The study area encompasses two regions: the sandy Ferlo and the cuirassed Ferlo. The sandy Ferlo in the northern part of the Ferlo Desert includes smooth dead ergs of the Quarternary era. Deep ferruginous soils developed on these fossil sand dunes. *Aristida mutabilis, Schoenfeldia gracilis,* and *Cenchrus biflorus* are characteristic species of the steppic grass layer. Fodder production ranges from 400 to 900 kg of dry matter/ha (8). Thorn shrubs and small trees (*Commiphora africana, Balanites aegyptiaca*) are scattered over the landscape.

The cuirassed Ferlo, in the southeastern part of the study area, has a more marked relief. An iron cuirass, which has been partly destroyed by erosion, is underlain by tertiary sandstones. Shallow and gravelly ferruginous soils occur on that iron pan. They include extensive areas with sealed surfaces, such that the herbaceous layer (*Zornia glochidiata*) is very scanty and unproductive. Fodder production usually does not exceed 100 kg dry matter/ha (*8*). *Pterocarpus lucens* forms monospecific communities in that arid woodland.

Methodology

Three representative drilled waterholes were selected for this study along a transect from northwest to southeast in accordance with the climatic gradient. Two waterholes are located on the sandy Ferlo, the third on the cuirassed Ferlo. Topsoil textures, determined on natural sites, vary from sand in Tessekre to loamy sand in Tatki and sandy loam in Revane (Figure 3).

Grazing and trampling were assumed to be related to the density of livestock near the waterholes. Two major concentric areas were identified. The affected zone, from the vicinity of the waterholes to a distance from 5 to 7 km, is where cattle impact the most. The undisturbed zone, beyond the previous circle, are areas where cattle rarely wander. Because of this very low use, these rangelands were considered as natural references for environmental features.

The study encompassed two areas: a morphological outline of soil surface processes (sealing, sand drifting, rills, and so on), studied in relation to the distance to the watering place and season (before and after the rainy season), and a quantitative assessment of several soil characters. On several points of a radial line drawn from the waterhole (denoted by Km 0), bulk density of the topsoil, albeit often covered with sand deposits, was measured with three replications to investigate possible soil compaction and to relate it to trampling. Soil samples were collected for mechanical and sieve analysis to determine deflation. Likewise, the amounts of organic matter were determined.

Soil surface features in the distant zones

Surprisingly, it was outside the zone affected by grazing and trampling that sealing most often occurred. However, the magnitude of the sealing varied widely from one study area to another (Table 1). Most bare and indurated spots in Tessekre were attributed to ancient and ruined termite mounds. Long trenches that were dug elsewhere revealed other possible patterns. Often in Tatki a broken calcareous horizon formed a shallow dome just below the crusted areas. Likewise, bare spots in Revane occurred mostly where the irregular boundary of the gravelly layer was closest to the surface. Thus, soil surface heterogeneity often was induced by a lateral variation of the underlaying soil.

Detailed studies of morphology, as well as sieve analysis, clearly demonstrated that sandy micromounds that bound the bare spots were aeolian deposits. Provided that rainfall was normal, as in 1981, runoff washed down sediments from these mounds, and crusted areas were covered again with sand. Consequently, an important areal reduction of bare surface was observed.

Soil surface alteration in the affected zones

Sandy Ferlo. Closer to the drilled holes, cattle tracks became more pronounced and numerous. Because the hooves of the herds pound micromounds and spread the sand over the crusted spots, the whole surface became completely covered with a sandy layer. Within a ring located between 0.5 km and 2.0 km from the watering points, wind-sorted surfaces were marked out by sand ripples. Evidence of an accelerated deflation

Table 1. Areal extent and average diameter of bare and crusted spots in the zones undisturbed by trampling.

Study Site	*Distance to Waterhole (km)*	*Areal Extent of Bare and Crusted Surfaces (%)*	*Average Diameter of Bare and Crusted Surfaces (m)*
Tessekre	7	8	2
Tatki	5	49	11
Revane	8	52	12

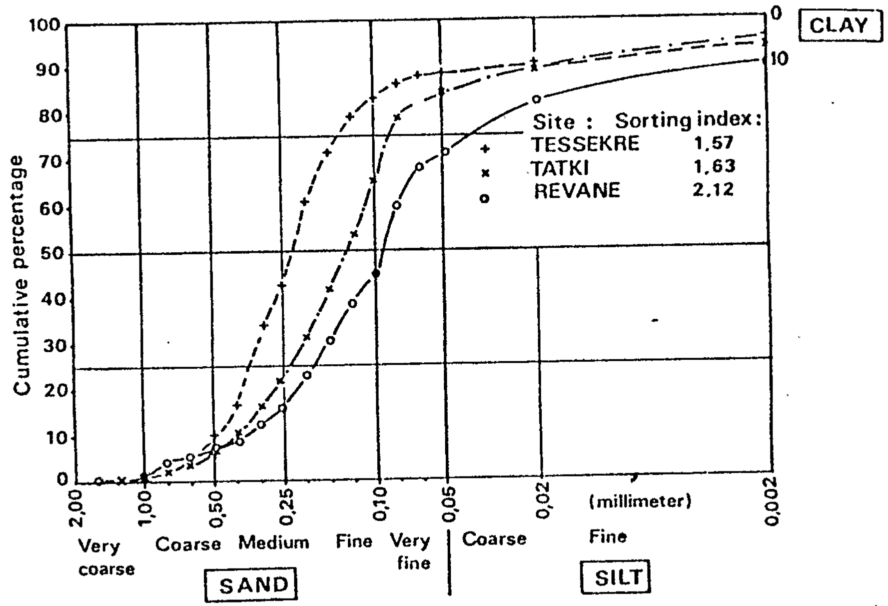


Figure 3. Grain size distribution curves and sorting indexes of samples (0-5 cm), from the zones undisturbed by trampling.

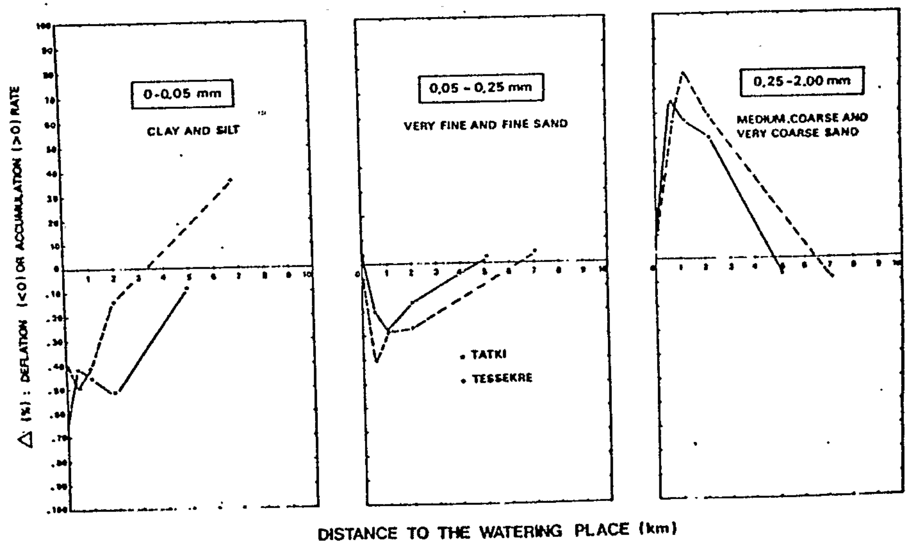


Figure 4. Effect of trampling, denoted by the distance to the waterhole, on the rate, Δ, of deflation or accumulation of three granulometric fractions. Δ (%) = (Ca-Cb)/cb, where Ca is the content in the sandy top layer or micromound (%), Cb is the content in the 5 cm directly underneath (%). When deflation occurs, Δ is less than 0. When accumulation occurs, Δ is greater than 0.

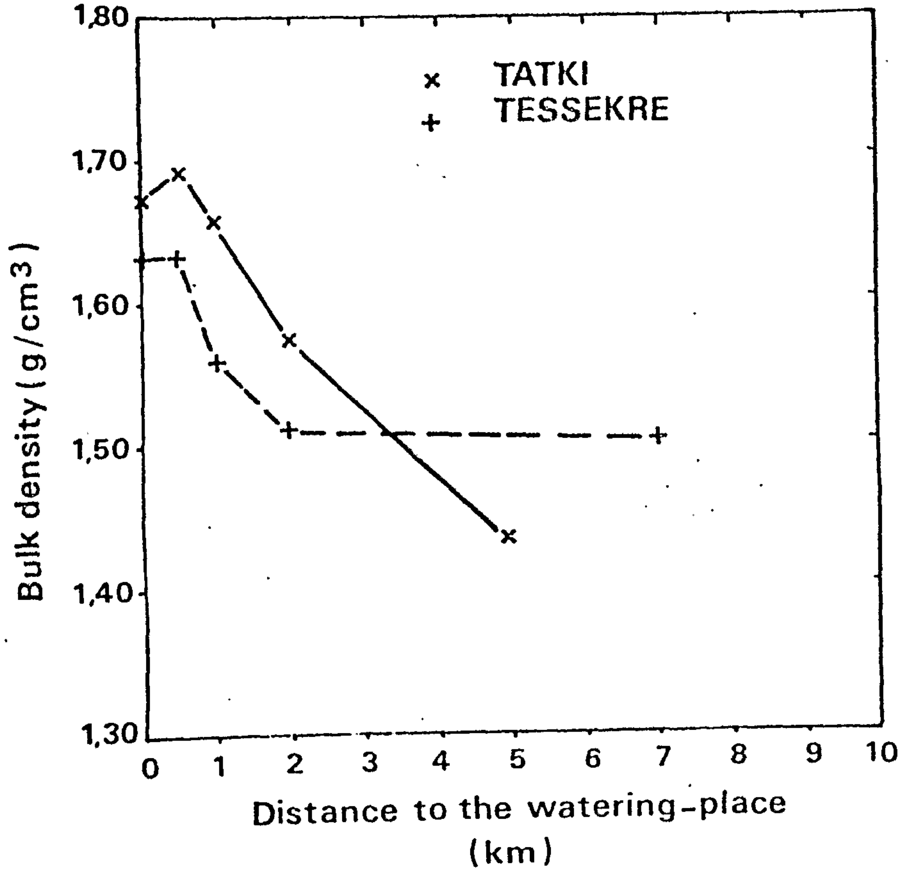


Figure 5. Effect of trampling, denoted by the distance to the waterhole, on bulk density of the layer directly under the trampled and sandy layer.

also was found through grain size analysis (Figure 4). Bulk density of the layer that underlies the sandy cover increased significantly as the distance to the wells decreased (Figure 5). Already low, the amount of organic matter was reduced further within the grazed ring. However, high values, resulting from cattle casts, were found for samples collected near the watering points (Figure 6). The devastation that resulted from grazing and trampling by late in the dry season was overwhelming. Yet a return of rains showed how misleading this appearance can be in terms of productivity (Figures 7 and 8).

Cuirassed Ferlo. In contrast to the sandy Ferlo, the cuirassed Ferlo suffered from severe accelerated water erosion. Plant communities were de-

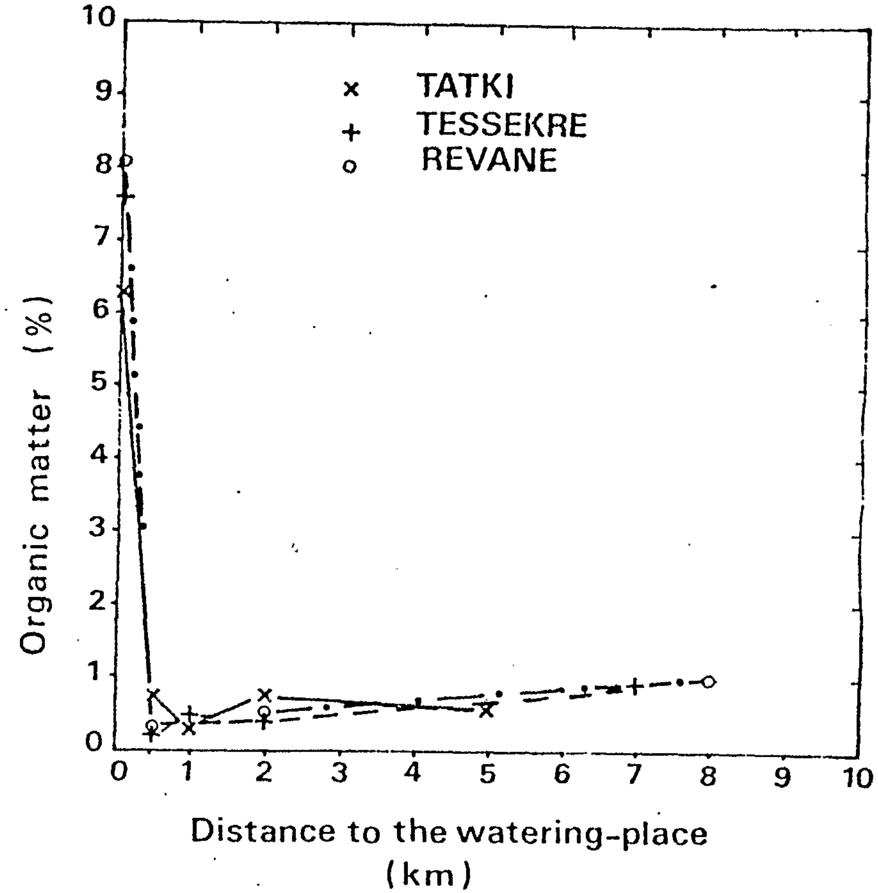


Figure 6. Effects of grazing and manure application on the organic matter content around three waterholes.

generated, allowing no hope of rapid recovery (Table 2). Closer to the Revane well, marks of a desolating deterioration were more and more conspicuous. Runoff on bare and crusted spots triggered sheet erosion, displayed by microcliffs and other pedestal features. Another stage was reached when linear erosion occurred amid the stripped surfaces, associating rills and small gullies to sand drift (Figure 9), emphasizing microrelief features. As a result, irreclaimable havoc occurred.

Discussion

Deterioration of vegetative cover. Arguments involving the actual effect of animal husbandry on vegetative degeneration have been presented in a

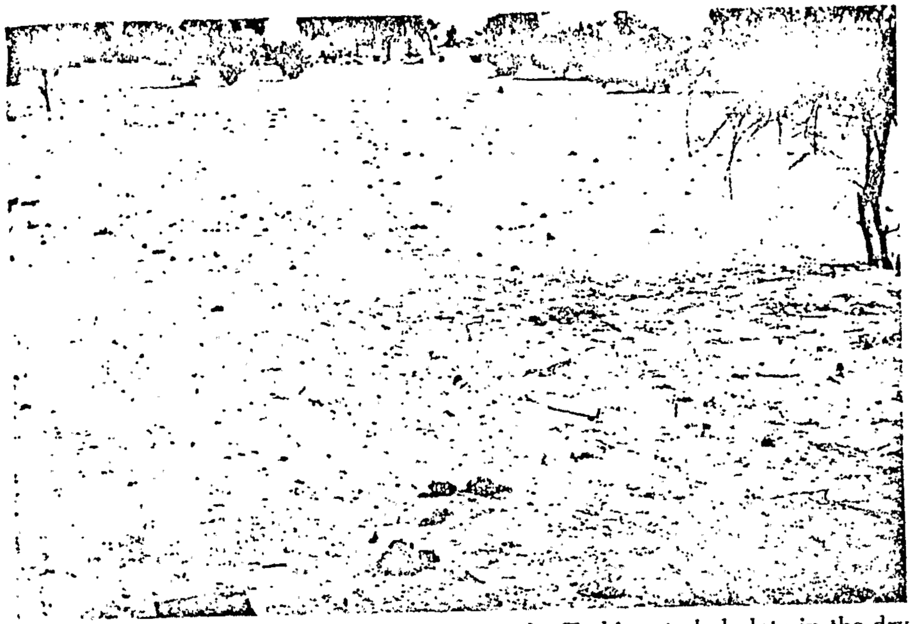


Figure 7. Bare sandy soil surface 2 km from the Tatki waterhole late in the dry season (May).

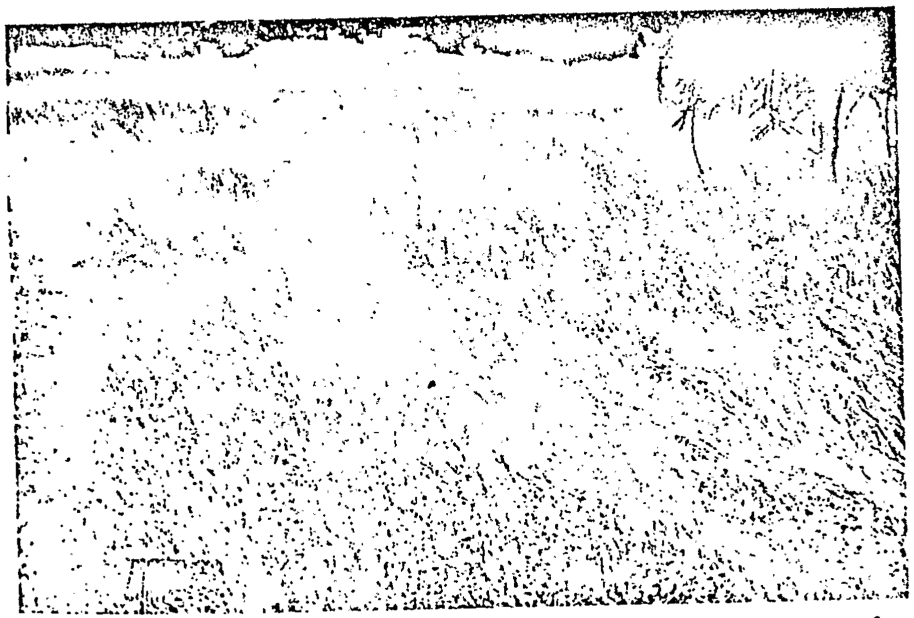


Figure 8. The same location shown in figure 7 covered with palatable grasses after the rainy season (November).

Table 2. Number of trees late in the dry season at various distances from the waterhole at the Revane site.

Distance to Well (km)	Number of Trees by Tree Height				
	0-0.5 m	0.5-1.5 m	1.5-2.5 m	>2.5 m	Total
8	128	127	160	140	555
6	233	67	67	73	340
1.5	83	53	7	7	150

variety of studies carried out in the Ferlo. Within a dry period of 5 years, tree losses amounted to 50 percent in a fenced reserve located 25 km from Tatki, without reference to any effect of browsing (*19*). Such observations do not weigh in favor of the spontaneous regeneration of protected grasslands, as often mentioned (*2*, *13*). Even more amazing is the significant increase of fodder productivity combined with the improvement of quality, in terms of palatibility, that have been clearly pointed out in the neighborhood of watering points in the sandy Ferlo (*5*, *6*, *23*). Two major causes can be assumed. First, as mentioned earlier, features of trampled materials are very similar to those of a plowed layer, the mulch effect of which allows complete infiltration and limits evaporation. As a result, such a layer is a more suitable breeding ground for grasses than the undisturbed soil. Secondly, cattle are still herded during the rainy season to the natural ponds so that deferred grazing is permitted, allowing vegetation

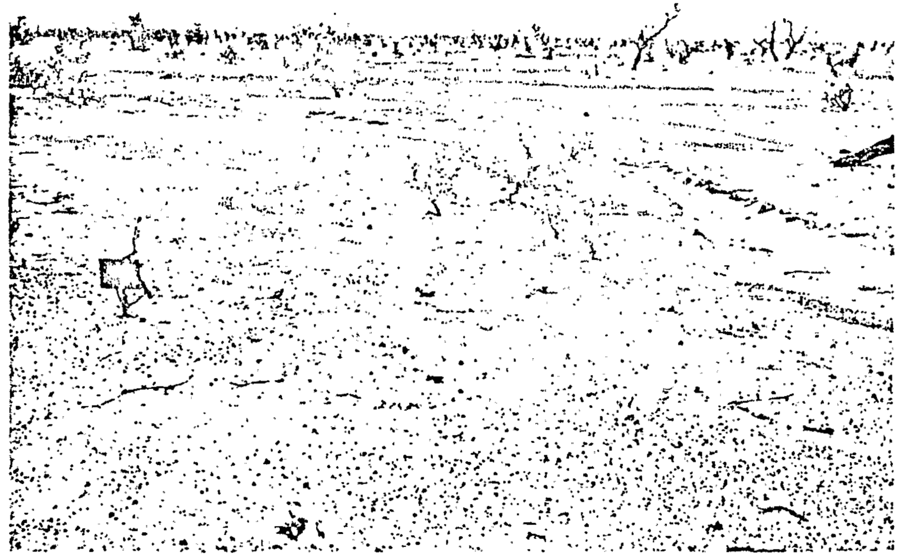


Figure 9. Ruined grassland, 2 km from the Revane waterhole.

near the drilled-holes to recuperate (3).

On the other hand, remote sensing analysis of aerial photographs from 1954 and 1978 revealed that ruined areas of the cuirassed Ferlo were associated with human settlements (25). Various lines of evidence suggest that the impact of drought has been seriously aggravated by the severe damage done by browsing and woodcutting. With respect to their livestock carrying density, the grasslands of Revane can sustain a maximum cattle population of 1,200, yet the actual number of cattle exceeds 1,500 (8, *16*). Thus, contrary to the sandy Ferlo, that region experiences a serious overgrazing problem.

Soil compaction. As reported by Thompson (*21*), Beckman and Smith (*4*), and Lagocki (*14*), trampling induces soil compaction. This study illustrates such effects in terms of bulk density in the sandy Ferlo.

Soil crusting. In contrast to the observations by Mott, Bridge and Arndt (*17*) in Australia and by Boudet (7) and Breman and associates (*10*) in Mali, soil crusting in the sandy Ferlo cannot be attributed to grazing and trampling because it occurs mainly in the furthermost zone from the watering points and even in a study reserve protected since 1969. Crusting must be the result of a complex web of natural factors involved in a cyclic pattern (Figure 10), which can be roughly outlined as follows:

First, during periods of below average rainfall (the last drought, for instance), plant resilience depends upon the thickness of the epipedon. For spots located directly above a domed calcareous layer or above shallow gravelly materials, moisture shortage is assumed to cause the collapse of plant communities. Moreover, meager amounts of organic matter make these soils very prone to crusting, even under low rainfall (22). Sealing is combined with a granulometric segregation so that sand is removed easily, then trapped by remaining grasses. This results in an increase of soil surface heterogeneity. Thus, climatic, plant, and soil factors are included in that process.

Second, during normally wet periods, for example, in 1981, the first rains erode the micromounds, covering bare spots with sand. As a result, seedling emergence is promoted and previously crusted and barren areas are gradually recolonized. Leprun (*15*) also described such a phenomenon in Malinese grasslands.

Wind erosion. In its early stages, wind erosion is not easy to identify morphologically. Its insidious effects must be detected by grain size analysis. Trampling adversely affects soils of the Sahel belt (*1*, *9*, *13*). Yet this study shows that fine sand movements do not occur most where trampling is the most intense, that is, in the vicinity of the watering places, but where numerous cattle tracks are coupled with extremely low values of

organic matter content, namely, within the 1- to 2-km ring. These results illustrate the value of cattle manure applications on light-textured soils, as mentioned by Chandra and De (*11*).

Water erosion. Water erosion that occurs in the cuirassed Ferlo can be attributed to a complex interaction of several factors: (1) Environmental factors—vulnerable soil texture, shallow impervious soils, long hillslopes, and scanty vegetation. (2) Drought—decay of vegetative cover is triggered by depleted water storage. Moreover, this process is encouraged by a widespread surface sealing that reduces the effective-rainfall, leading to

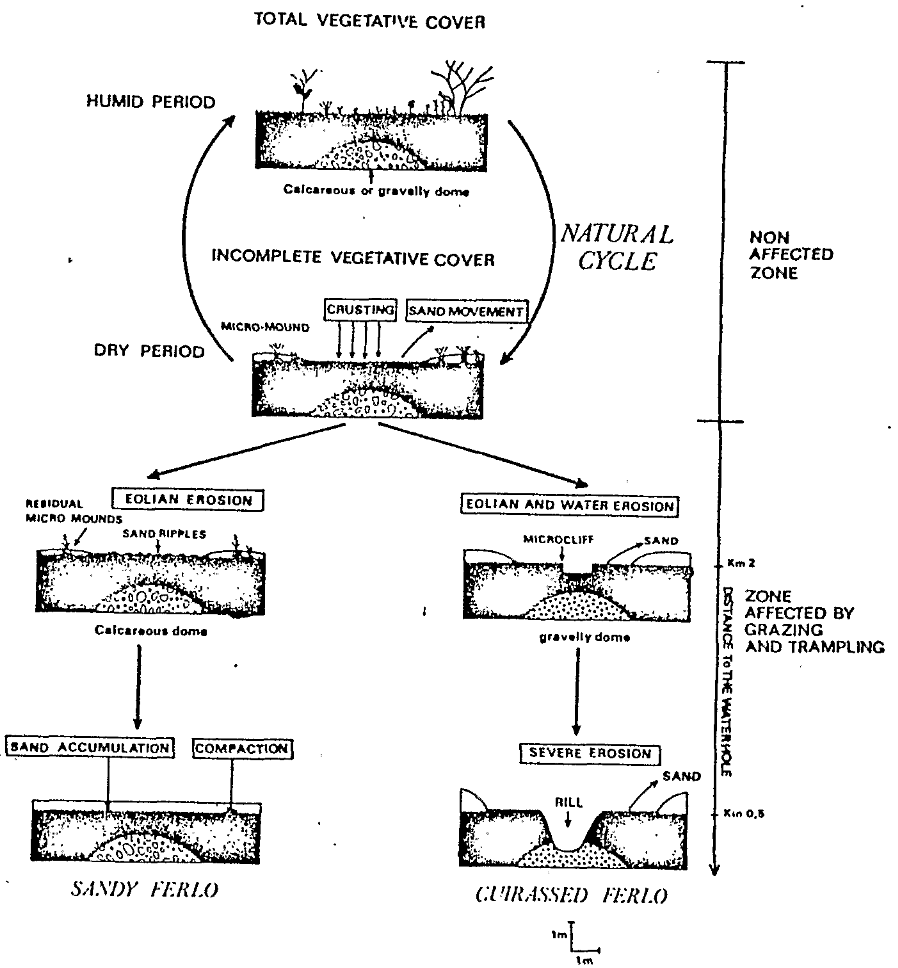


Figure 10. Schematic natural cycle and evolution of soil surface features related to the distance from the waterholes in the sandy Ferlo and cuirassed Ferlo.

further plant degeneration. (3) Animal husbandry—overgrazing due to errant cattle occurs rapidly because injured plant communities permit only a very low carrying capacity. Also, trampling by livestock converts their trails to channels for rill erosion.

Thus, within 3 decades, land abuse coupled with a frail environment has ruined the land inheritance for the foreseeable future.

Conclusions

Heavy trampling and intense grazing around waterholes cause land degradation in the Sahel belt. The magnitude of that deterioration depends upon the ecological surroundings. On one hand, observations on the sandy Ferlo show that plant degeneration is not invariably induced by animal husbandry. Regeneration can occur surprisingly fast, provided rainfall returns to normal. In these sandy regions, land damage occurs mainly in the form of wind erosion. On the other hand, any change that disturbs the frail balance of the cuirassed Ferlo (drought, enhancement of pastoral practices) leads to the much more extensive havoc created by accelerated water erosion.

It must be conceded, however, that some processes, such as soil crusting, result much more from the combination of several natural factors than from any impact of animal husbandry, which is too often unjustly blamed. Moreover, some practices, such as limited nomadism during the rainy season, must be considered as an interesting, spontaneous answer to the problem of overgrazing around the wells and, thus, proper land use.

Recommendations

Adequate measures to prevent and to combat land degradation in the southern fringe of the Sahara have been proposed repeatedly (*2*, *12*). Some of these propositions cannot be over-emphasized and should be urged:

► Assess the carrying capacity of the rangelands before undertaking any project, including an increase of livestock population. Development of a region must not be attempted, regardless of the environmental consequences.

► Gain willing participation of the pastoral communities in projects. In contrast to a widespread prejudice, enmity towards progress is not anchored in nomadic tradition.

► Establish tree-planted shelterbelts within a 1- to 2-km around the waterholes. These are the zones most subjected to deflation. Various experiments in the Sahelian countries have shown that afforestation cam-

► Restore the land, if necessary, with the help of an experienced staff. Unfortunately, good will is not sufficient and can even be dangerous. For example, deep, downhill plowing can promote rill erosion. Consequently, training should be implemented to spread the simple and efficient techniques of soil restoration beyond the limit of a small group of specialists.

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