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SAHEL-SUDANO DESERTIFICATION STUDY

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ABSTRACT

This study was initiated to evaluate the usefulness of Landsat data for monitoring the effects of desertification on arid and semi-arid lands. A study area was selected which encompasses parts of Mauritania, Mali and Senegal. It was located between 13°45' and 18°00' north latitude and 9°00' and 16°15' west longitude. This is an area where evapotranspiration exceeds precipitation annually. It is therefore very susceptible to moisture stress conditions, either climatic or man induced.

Several indicators of short, intermediate and long term desertification effects are illustrated and discussed. Short term effects are shown in a very fragile area where vegetation is evident during a higher precipitation year, 1976, but not during drier years, 1972 and 1977. The amount of water in stream and river channels is illustrated as a short term indicator. The extent of flooding in flood recession agricultural areas is also visualized.

Intermediate effects are apparent in flooding and the presence or absence of burn patterns. These reflect vegetative growth as influenced by precipitation. Long term effects such as sand dune encroachment onto arable lands is shown. Salinization of previously productive lands is also illustrated.

A soil resources map was produced and interpreted as a guide for locating specific areas where these long, short and intermediate

effects would be most likely observed and monitored. The need for and usefulness of accurate soils maps is discussed. These are best prepared on Landsat imagery and the mapping units defined on the basis of ground verification.

Landsat data is shown to be an effective tool for assessment of desertification. The multitemporal nature of the imagery is valuable in permitting comparisons of changes in both past and real time evaluations. Although the multispectral nature of Landsat data was not fully utilized in this study, it is undoubtedly one aspect of remote sensing which needs further evaluation. The correlation of Landsat data with ground observation could lead to the development of techniques for predicting real time and near future reaction of arid and semi-arid regions to desertification related stresses.

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INTRODUCTION

Desertification or desert encroachment, reduced to its simplest terms, is a reduction in the potential productivity of dry lands. More specifically, it is the lateral extension of areas characterized by sparse vegetation and low biological activity. The characteristics of desertification are commonly associated with arid and semi-arid climates which implies deficient rainfall and high temperatures. While Dregne (1977) alluded to desertification of humid regions (e.g. Great Plains), this report will make reference only to regions in or near arid and semi-arid zones. Polar regions also have areas which possess desert characteristics. Arid and semi-arid climates can be exclusive of high temperatures. Péwé (1974) estimated that polar deserts cover approximately 4,300,000 square kilometers in the northern hemisphere and 600,000 square kilometers in Antartica. However, semi-arid and transitional zones do not appear to exist and polar deserts interface directly with snow fields and glaciers. These regions are also of minor importance economically and sociologically.

Several factors and combinations of factors have been used to classify arid lands and to separate arid from semi-arid areas. One of the earliest, and possibly least successful, classifications was based on rainfall alone. The Sahara was excluded southward to the 250 mm isohyet and the southern margin of the semi-arid area was placed at the 400 mm isohyet. These oversimplifications ignore the functions of temperature and evapotranspiration as related to the

effectiveness of precipitation. This important link was proposed by Penck in 1910 in defining the boundary of drylands as the places where evaporation exceeds precipitation. The paucity of evapotranspiration data at that time, and continuing to the present, prevented general acceptance and application of Penck's thesis (Walton, 1969).

The significance of temperature was recognized by Köppen (Walton, 1969) in 1918. Desert was separated from steppe by the 200 mm isohyet where the mean annual temperature was between 5°C and 10°C and followed the 320 mm isohyet where the mean annual temperature was 25°C. The margin between steppe and humid regions has also been located at the 400 mm isohyet for 5-10°C temperatures and at the 640 mm isohyet for 25°C (Walton, 1969).

De Martonne (1926) utilized temperature and rainfall data to produce an aridity index

$$\frac{P}{T + 10}$$

where P is mean annual precipitation in mm and T is mean annual temperature in degrees centigrade. Desert was defined with an aridity index of less than 5 and the steppe boundary was represented by a value of 10. This was further modified in 1942 (Walton, 1969) to account for seasonal distributions.

$$\text{aridity index} = \frac{\frac{P}{T + 10} + \frac{12p}{t + 10}}{2}$$

Where p is average precipitation and t is average temperature of the driest month.

Although these approaches appeared reasonable, they were still simplistic in considering only climate. Many significant factors were overlooked. Such factors as soil type and texture, soil moisture holding capacity, wind velocity, relative humidity, vegetation cover and land use are also significant although difficult to accommodate with simple equations.

Thornthwaite (1948) proposed a precipitation-effectiveness index, or $\frac{P}{E}$ ratio. The index is calculated for each month. P being precipitation and E evaporation, summed for the year and multiplied by 10. Where evaporation data were unavailable it could be calculated:

$$\frac{P}{E} = \Sigma^{12}\ 115\ \left(\frac{P}{T-10}\right)^{\frac{9}{10}}$$

where T is mean monthly temperature. It has been shown that P/E ratios are a useful and accurate guide to climatic differentiation of arid regions. The P/E value for the semi-arid margin is 20 and 40 for the arid margin.

Meigs (1953) applied Thornthwaite's index for determination of the earth's arid regions. He further refined the groupings into regions with similar seasonal distribution of precipitation and temperatures for the coldest and warmest months. Semi-arid, arid and extremely arid zones were identified.

Applying the criteria of Meigs, there are 21,243,000 square kilometers of semi-arid land, 21,803,000 km^2 of arid and 5,812,000 km^2 of extremely arid land in the world, approximately 33% of the earth's

land surface excluding cold, arid regions (Dregne, 1976). Based on great soil groups maps, 28% of the world's land surface is arid (Kellogg and Orvedall, 1969) but more recent estimates based on soils indicates 31.5% of the world surface is arid (Dregne, 1976). Based on vegetation (Shantz, 1956), there are 7,045,000 km^2 of semi-arid land, 33,411,000 km^2 of arid and 6,294,000 km^2 of extremely arid land, 32% of the earth's surface. The total, 46,750,000 km^2, agrees well with Meigs' climatic-derived cumulative total of 48,858,000 km^2, but the distribution among the three categories (i.e. semi-arid, arid, extremely arid) is quite different.

Based on these independent estimates, approximately one-third of the earth's surface is influenced by limited moisture. This has a strong influence on man's habitation of these areas. Conversely, man appears to be having an influence on lateral expansion of arid regions into otherwise arable lands. As reported by Dyer (1955), a Desert Encroachment Commission was formed in 1950 and concluded that the responsible agent for desertification in Africa was man through overgrazing and abuse of land and water resources. At a United Nations conference on desertification held in Nairobi, Kenya (1977) it was pointed out that both crop land and grazing land were deteriorating under the influence of man and livestock. The decrease in productivity, while definitely attributable, at least in part to man, may also be in concert with climatic shifts. With or without climatic influences, growing populations increase pressure on fragile ecosystems as demands for food, fiber and space increase.

The term desertification implies a progressive expansion of a less desireable climate and its direct, detrimental influence on soil and plant resources. The influence of man, in this case, is tantamount to a change in climate. As desertification continues, the ecosystem regresses resulting in decreased biomass in desired grazing species, introduction of unfavorable species, increased susceptibility to soil erosion, and poorer living conditions for humans (Dregne, 1977). This spiraling decay of the environment increases during droughty years when overgrazing creates an unmanageable load on the range vegetation. The inevitable migration of nomads further complicates the situation. Dryland farming also suffers because of the lack of conservation control of wind and water erosion.

Study Area

In a large belt across Africa, north of the Equator and south of the Sahara, lies the transitional zone or ecotone that separates the arid climate from the more humid interior. From the mid-1960's until present, traditional methods of growing agricultural production in this area have failed to meet growing demands of the population. This inadequate production has been brought on by recent, severe droughts in the region. Populations of man and domestic animals have rapidly increased in western Africa as a consequence of recent improvements and application of modern medical, scientific and technological knowledge. In dry years, the demands for food greatly exceed the limited production capability of the traditional agricultural practices. An equally serious and significant contributing factor, is the long term effect of degradation of soil and vegetation resources in these arid and semi-arid areas. This can result in permanent and irreversible changes in plant communities and landscapes. This project will attempt to identify the applicability of Landsat imagery to identify factors which indicate desertification in western Africa.

Specifically, the study area encompasses parts of Mauritania, Mali and Senegal. It is located between 13°45' and 18°00 north latitude and 9°00' and 16°15' west longitude.

This zone, a part of the Sahel, is generally hot with limited water supplies. Precipitation occurs only during a few months of the northern hemisphere summer. The amounts range generally from a mean annual of 100 mm in the north to 1000 mm in the south (Davey, et al., 1976).

The population of Mauritania is estimated at 1,500,000; the urban population representing 64% of the total and the rural population accounting for the remaining 36%. The nomadic population is estimated at 96,000 (FAO, 1977a). The population of Senegal is estimated to be 5,333,000 in 1978 (FAO, 1977b).

A majority of the people are directly engaged in agriculture. The staple food crops are millet and sorghum. Some maize and rice are produced. Peanuts are raised commercially. Cattle, sheep, goats and camels are the principle livestock raised.

The general climate in the study area is characterized by a short, summer rainy season and an extended dry period the remainder of the year. The temperatures are warm throughout the year. Data from 1972 through 1977 are summarized in Appendix A. The locations of the 11 stations reported are indicated by solid squares on the Transportation Map.

As indicated in the introduction, temperature and precipitation are not the best climatic indicators when the principle concern is the production of crops or biomass. Therefore, potential evapotranspiration (PET) data were assembled and combined with precipitation (PPT) data to produce a measure of the incident moisture availability to vegetation. Errors are inherent in this approach. The moisture holding capacity of the soil, individual crop water demands, and antecedent soil moisture conditions were not considered

because of lack of data. The data were extracted from Davey et al. (1976) and were available from four sites within the study area. All sites were located at 14.00° west longitude. They were assigned to zones of varying precipitation from 400 to 1000 mm per year. This zonation was implied in the data source.

Mean monthly precipitation values are given but the data source did not indicate the period of record. It is recognized that mean values must be used with great care in arid climates because of extreme variability in the nature of precipitation event. PET was calculated by the Penman equation (1948).

The significance of Tables 1, 2, 3 and 4 is in the precipitation minus PET column. A negative value indicates that the moisture demand exceeds the precipitation supply and a positive value indicates more than adequate precipitation. The precipitation amounts presented represent a 50% probability of occurrence. Therefore, statistically, there is an equal chance of receiving either more or less precipitation than that tabulated. At the northern site (Table 1) rainfall exceeded PET by 18 mm in only one month, August. Progressing southward along the 16° longitude line, this changed to 2 months, then three months and the amount of deficit water decreases from 1484 mm to 620 mm per year. This exerts a tremendous influence on the type of agriculture and grazing and its ability to sustain production during drought periods. This thesis will be expanded in later sections of the report.

Table 1. Climatic data for 400 to 500 mm annual precipitation zone. Site location: 16.0° north latitude, 14.0° west longitude.

Month	Precip. mm	PET mm	Precip.-PET mm	Temp. °C
Jan.	0	144	-144	23.7
Feb.	0	153	-153	26.8
Mar.	0	185	-185	28.7
Apr.	2	199	-197	30.4
May	5	219	-214	33.5
June	30	175	-145	33.3
July	90	152	-62	31.7
Aug.	160	142	+18	30.6
Sept.	100	130	-30	30.4
Oct.	25	135	-110	31.0
Nov.	2	132	-130	28.0
Dec.	0	132	-132	24.4
TOTAL:	414	1898	-1484	Ave: 29.4

Table 2. Climatic data for 500 to 700 mm annual precipitation zone. Site location: 15.4° north latitude, 14.0° west longitude.

Month	Precip. mm	PET mm	Precip.-PET mm	Temp. °C
Jan.	0	144	-144	24.6
Feb.	0.	148	-148	27.3
Mar.	0	181	-181	29.3
Apr.	2	201	-199	31.1
May	5	219	-214	33.8
June	50	174	-124	32.9
July	130	150	-20	31.1
Aug.	220	135	+85	29.8
Sept.	150	128	+22	29.7
Oct.	40	138	-98	30.6
Nov.	2	128	-126	28.1
Dec.	0	129	-129	24.9
TOTAL:	599	1875	-1276	Ave: 27.1

Table 3. Climatic data for 700 to 900 mm annual precipitation zone. Site location: 14.4° north latitude, 14.0° west longitude.

Month	Precip. mm	PET mm	Precip.-PET mm	Temp. °C
Jan.	0	144	-144	25.4
Feb.	0	148	-148	27.9
Mar.	0	188	-188	30.0
Apr.	2	200	-198	32.5
May	10	215	-205	33.5
June	100	172	-72	31.5
July	180	138	+42	28.9
Aug.	270	123	+147	29.7
Sept.	200	123	+77	28.0
Oct.	60	133	-73	29.8
Nov.	2	126	-124	27.9
Dec.	0	120	-130	25.5
TOTAL	824	1830	-1006	Ave: 29.2

Table 4. Climatic data for 900 to 1100 mm annual precipitation zone. Site location: 13.7° north latitude, 14.0° west longitude.

Month	Precip. mm	PET mm	Precip.-PET mm	Temp. °C
Jan.	0	143	-143	25.9
Feb.	0	149	-149	27.8
Mar.	0	184	-184	30.2
Apr.	2	193	-191	32.5
May	25	210	-185	32.6
June	135	163	-28	30.3
July	220	131	+89	27.7
Aug.	300	117	+183	26.9
Sept.	400	117	+283	27.2
Oct.	75	129	-54	28.1
Nov.	5	123	-118	27.5
Dec.	0	123	-123	25.5
TOTAL	1162	1782	-620	Ave: 28.5

Soils in the Study Area

Soils of arid regions possess many characteristics which are unique and different from the soils of more humid regions. Texture, structure, depth, salinity, reaction, carbonate content and organic matter content are some properties which may vary widely from more normal arable soils. The differences may be attributed to the age of the material, mineral composition, vegetation, landscape position, wind and water erosion, past climates, seasonal climatic variability, man's activities and other environmental factors. The various combinations of factors and the degree of expression of each produce a variability in arid soils as diverse as that under more humid and more intensively studied soils.

One of the characteristics of the arid zones is that the soils, landscapes and vegetation exist in a very delicate equilibrium condition. This biophysical environment is extremely fragile and very close to instability at most times. The slightest perturbation introduced by man or nature which causes a shift in the energy balance of this system can completely and irreversibly disrupt the equilibrium. Recovery from a protracted drought or even a single plowing of the land can be very slow. Once the cover of a land is removed or disturbed, the processes of soil erosion may result in the formation of gullies or sand dunes which permanently alter the landscape and seriously reduce the productivity of the soil.

Africa has the largest continental area of arid region soils. It is estimated that there are 17,660,000 km^2 of arid soils, 50.2% of the continent (Dregne, 1976). All of the soils in the study area are included under the broad classification of arid soils. These

soils were mapped for the study area at a scale of 1:1,000,000 on Landsat imagery (a mosaic of 15 scenes). Each soil mapping unit delineated was classified in the USDA-SCS system of soil taxonomy (Soil Survey Staff, 1975). It should be borne in mind, however, that both the map and classification are somewhat tentative. The reason for this is a lack of ground observation. The information presented is therefore based on normally predictable soil-landscape-climate interrelationships and not on actual data.

A brief discussion of the U.S. Department of Agriculture system of soil taxonomy is needed to permit a more meaningful interpretation of the soils map. The system is a hierarchial ordering based on natural relationships among soils. Within the hierarchy, soils are grouped into taxa in successively larger numbers from higher to lower categories.

In order of decreasing rank and increasing number of classes, the categories are Order, Suborder, Great Group, Subgroup, Family and Series. There are ten orders. At this highest category, soils are separated on the basis of the presence or absence of features which indicate the dominant set of soil forming factors which have occurred in the past. Soils form when climate and living organisms act on parent material over time as conditioned by topography. These factors have geographic significance and are mappable over large regions.

Forty seven suborders are recognized at present. The differential at this second categoric level include properties which influence soil genesis and are important to plant growth. These include such characteristics as the relative age of the parent material, the degree of erosion and the moisture and temperature regimes. Regional influences are implicit in these taxa.

There are 185 great groups identified and defined at present. The whole soil as well as the moisture and temperature regimes are considered in the taxa at the level of separation. Each taxon is defined based on close similarities in kind, arrangement and degree of expression of horizons together with soil moisture and temperature regimes.

The 970 recognized subgroups are separated on the basis of degree of soil development. Some subordinate criteria are also used but they are mostly internal properties of soils. The 4500 families and 10,500 series in the United States are differentiated on the basis of physical and chemical soil properties.

The overall effect of this hierarchial ordering is the development of close relationships between the physical dimensions and the spatial arrangement of the various taxa. Progressing downward through the categories, the differentiae become more specifically measurable.

Six of the ten soil orders were located in various parts of the study area. These can be seen on the soils map and are listed in the accompanying soil legend. The following portion of the report will present a brief description of the soil mapping units.

I. Entisols

Entisols are mineral soils which have little or no evidence of the development of pedogenic horizons. There are no accessary soil characteristics. They are soils in the sense that they support plants

but they have minimal horizon development. Entisols are found in every climate and under most types of vegetation. These soils have little or no horizonization. They are found on very young parent material or on slopes where erosion rates exceed the rates of soil development; thus surface material is removed before it can be incorporated into a soil profile. In the study area these soils are found primarily north of the Senegal River.

I.1. PSAMMENTS: These are Entisols which are formed in poorly graded sands of shifting or stabilized sand dunes, sandy natural levees and beach deposits. They have low water holding capacity and are naturally infertile. When they are dry and bare they are very susceptible to blowing and wind erosion.

I.1.1. TORRIPSAMMENTS: These are psamments which have a torric moisture regime. They are dry in all parts of the soil more than half of the time when the soil temperature is greater than 5°C at a depth of 50 cm and never moist for more than 90 consecutive days. In the study area these soils were broken into seven mapping units based on dune morphometry and interpreted sand depth.

I.1.2. AQUIPSAMMENTS: These soils are a special type of psamment which have been mapped in the area of Lac Rkiz. They differ from normal psamments by being flooded and saturated with water for periods of time. This inundation somewhat restricts their use for arable agriculture.

I.2. AQUENTS: These soils are the wet Entisols. They may occur in tidal marshes, on river deltas or flood plains or under any situation where sandy soils are saturated with water for extended periods. These soils may have a fairly high organic carbon content in the upper 25 cm.

I.2.1. NATRIC FLUVAQUENTS: These soils are affected by high sodium content and are dispersed. They have been mapped on the deltas of the Senegal and Saloum Rivers where salt waters intrude periodically.

I.2.2. FLUVAQUENTS: These are Aquents which have a fluvial origin occurring along streams and rivers but without severe sodium influences. These soils have been mapped along the flood plain of the Senegal River where they are subject to frequent flooding.

I.3. ORTHENTS: The Orthents are Entisols which result from extreme erosion, either geologic or man induced. In either case, all pedogenic horizons have been removed. The result can be denudation of thick parent material or removal of unconsolidated material to such a degree that bare, consolidated rock is at or very near the surface. These soils have been mapped in the northeastern portion of the study area. They are essentially unproductive soils for crops or rangeland.

I.3.1. XERORTHENTS: These are Orthents which are extremely dry at all times of the year.

I.3.2. TYPIC USTORTHENTS: These soils have a ustic moisture regime. Ustic moisture regimes have some moisture for less than 90 consecutive days. However, they are more moist than the Xerorthents (I.3.1.).

I.3.3. LITHIC USTORTHENTS: These soils are similar to typic Ustorthents except they are very shallow. Within the mapping unit, bare rock exposures are very common.

II. INCEPTISOLS

Inceptisols are soils formed on relatively young geomorphic surfaces. They exhibit some pedogenic horizon development. The texture is normally finer than loamy sand and the water holding capacity is moderate. These soils have water available to plants for more than three months during the warm season. The surface horizon contains somewhat more organic carbon than Entisols and is therefore darker colored. These soils were mapped in the Gorgol region of Muaritania and immediately south of and adjacent to the Senegal River in Senegal.

II.1. TYPIC USTOCHREPTS: These are Inceptisols formed in thick, Holocene deposits with thin, fairly light colored surface horizons. The mean annual soil temperature, at a depth of 50 cm, is greater than 22°C and the mean summer and mean winter soil temperatures may be less than 5°C. This defines an isohyperthermic temperature regime. Under these conditions, the soils are dry for at least 90 cumulative days each year and contain some moisture for 90 consecutive days or more.

III. ARIDISOLS

The unique properties of Ardidisols are a lack of water available to mesophytic plants for extended periods, a lack of organic carbon to significantly darken surface horizons and the presence of one or more pedogenic horizons. During the warm season, there is no period of 90 days or more when soil moisture is continually available for plants, except in places where the water table is close to the surface. In that situation, salts are also concentrated and restrict plant growth.

III.1. NATRARGIDS: These are soils which are characterized by clay translocation in the profile. These soils normally occur on gently sloping topography with very little water erosion evident. The surface may exhibit some influence of sorting by wind. The lower horizon of clay accumulation is influenced by high salt and sodim accumulation. They are mapped primarily in the area south of the Senegal River and north of Vallie due Ferlo. Natural vegetation consists of ephemeral grasses and forbs with scattered xerophytic shrubs such as *Acacia* spp.

III.1.1. TYPIC NATRARGIDS: These are slowly permeable soils with a fine textured subsoil. They have a ustic moisture regime and an isohyperthermic temperature regime. As the subgroup name implies, they represent the typical, or central concept of Natrargids.

III.1.2. AQUIC NATRARGIDS: These soils differ from typic Natrargids in having a darker surface horizon as a consequence of a higher organic carbon content. In addition, these soils may have excess

moisture in the upper one meter at some time during the year. This may result from runoff water collecting from higher landscapes. They are primarily used for grazing although forage production may be limited, especially during dry years.

III.1.3. HAPLIC NATRARGIDS: These Natrargids have a very dense horizon of clay accumulation which is very high in sodium content.

III.2.1. TYPIC CAMBORTHIDS: These soils have one or more pedogenic horizons but do not have an horizon of extremely high clay content or high sodium content. They may have a high salt content at a depth of 1 m. They are brownish to reddish soils with a ustic moisture regime and an isohyperthemic temperature regime. They can be productive grazing lands but are susceptible to drought and overgrazing. Under these adverse conditions, they may be susceptible to wind erosion.

IV. ALFISOLS

The central concept of the Alfisol order is that of a soil with a light brown surface, a subsurface horizon which shows some pedogenic clay translocation and contains sufficient moisture for plant growth during the plant growth season.

IV.1. NATRUSTALFS: The Ustalfs are the dry Alfisols. The soil color is usually reddish as a result of good drainage. Many of these soils have a savanna type vegetation with xerophytic trees. They are commonly used for grazing but can be productive crop land. In that respect, they are susceptible to drought conditions. The Natrustalfs

have a thin surface horizon and the subsoil shows the influence of high sodium content. These soils were mapped in the southern and southeastern portions of the study area.

IV.1.1. TYPIC NATRUSTALFS: These soils are not as well drained as other Ustalfs. They may be grey in the subsoil because of water saturation at some time of the year.

IV.1.2. AQUIC NATRUSTALFS: These soils are more poorly drained than the typic Natrustalfs (IV.1.1.) and are therefore grayer and have a thicker dark surface horizon. They are saturated with water within 50 cm of the surface at some time in all years.

IV.2. HAPLUSTALFS: Haplustalfs are relatively thin, reddish brown soils. They do not have excessive salts or sodium in the upper 1.5 m of soil. The textures are finer than loamy sand.

IV.2.1. VERTIC HAPLUSTALFS: These soils typically have fine textures with expanding type clay minerals. As such, they crack open during dry periods and the cracks close during moist periods. They are found on gentle to moderate slopes. They are good grazing lands and crop production is possible because of the high water holding capacity associated with the fine textures.

IV.2.2. TYPIC HAPLUSTALFS: The central concept of the typic subgroup of Haplustalfs is fixed on freely drained soils that are moderately deep or deep to hard rock. These soils show evidence of pedogenesis. They are used for grazing or production of drought tolerant crops.

IV.2.3. OXIC HAPLUSTALFS: These soils differ from the typic subgroup by having more translocated clay in the subsurface horizons. They are more severely weathered and therefore leached and less fertile. These soils are deeply leached and are transitional to outs of the Oxisol order

IV.2.4. AQUULTIC HAPLUSTALFS: These soils are wetter than either typic or Oxic subgroup soils and more weathered than typic. They have a high clay content in subsurface horizons but are not as leached as the Oxic subgroup soils. Therefore they tend to have higher fertility.

IV.3. PALEUSTALFS: These are thick, reddish or red soils formed on gentle slopes. Natural vegetation is savanna type. The soils are freely drained, weathered and leached to a depth of 2 meters.

IV.3.1. TYPIC PALEUSTALFS: The central concept of this subgroup is fixed on a freely drained, well developed soil. The texture is loam or finer. These soils have some expanding type clays. The soils tend to be arid but with sufficient moisture for range production.

IV.3.2. UDIC PALEUSTALFS: Soils in this subgroup differ from the typic subgroup by being more deeply leached. They exist on more gentle slopes and contain more moisture for longer periods of time.

IV.4. RHODUSTALFS: Only one subgroup was mapped in this group. Udic Rhodustalfs are dark red and thinner than Paleustalfs. They generally occur on steeper, more eroded slopes. Because of this, they tend to be somewhat dry and best suited for grazing.

V. VERTISOLS

The central concept of the Vertisol order is that of soils with a high clay content. These clays are of the 2:1 lattice expanding type (montmorillonitic) which results in cracking during the dry season and characteristic microrelief called gilgai. These soils are deep to very deep. Clay content is at least 30% in the upper 50 cm. Cracks extend downward from the surface and are at least 1 cm wide at a depth of 50 cm.

V.1. TORRERTS: Torrerts are Vertisols of the arid climates. The cracks may remain open throughout most of the year or may fill with wind blown material. During the rainy season, the cracks remain closed for less than 60 days. They generally occur on very gentle slopes. Only one subgroup is recognized in the study area, Typic Torrerts (V.1.1.). Under these climatic conditions, the gilgai is quite subdued.

VI. OXISOLS

Oxisols are reddish, yellowish or grayish soils on gentle slopes. They are mixtures of quartz, kaolinite, free iron and aluminum oxides and organic matter. They are extremely weathered soils with very diffuse horizons. They are weathered to a great depth producing a very thick regolith. An arbitrary depth limit has been placed at 2 meters. The rapid permeability of these soils plus the gentle slopes makes them resistant to erosion when cultivated. They are, however, very infertile. With proper management, they may become productive soils.

VI.1. USTOX: These red soils are dry in all parts for extended periods during the year. However, they do contain plant available water for at least 90 days during the rainy season. The native vegetation is savanna or deciduous forest. They can produce some annual crops without irrigation.

VI.1.1. TYPIC HAPLUSTOX: These are freely drained soils with a fine textured subsurface horizon. These soils have a relatively high potential for range or annual crop production.

VI.1.2. ULTIC HAPLUSTOX: These differ from the soils of the typic subgroup in being finer textured and deeper as a result of more intensive weathering. They are the most severely weathered, deepest soils in the study area.

LAND USE IN THE STUDY AREA

Six general types of land use were mapped in the study area. Interpretations of the Landsat imagery were greatly assisted by Mr. Bill Pearson, AID/AFR/SFWA, Department of State, Washington. The delineations follow the soils map closely since soils reflect both climate and vegetation. It is these environmental factors which determine, to a large degree, the land use in an area. The following section discusses the mapping units used on the land use map. As with the soils map, this should be considered preliminary and subject to revision depending upon ground survey data collection.

D. SAND DUNES

Among the more prominent features of the landscape are the dune formations along the northern edge of the study area. These are areas of shifting, loose sand dunes which assume a variety of forms. Interdune areas may have some vegetation. The alignment of dunes is indicative of prevailing wind directions. Longitudinal dunes are aligned parallel to the wind whereas transverse dunes are aligned normal to wind directions.

D1. Barren Sand Dunes: These are dunes with little or no vegetation. They are shifting sands which support no agricultural activity.

D2. Semi-Stabilized Dunes: In low lying, interdune areas, some vegetation is produced. This is mostly sparse, short annual grasses.

In years of average or above precipitation, sufficient vegetation exists to support seasonal, nomadic grazing of livestock. During dry years, the vegetation is not present in sufficient amounts to permit grazing and this results in increased pressure in other areas where grass may exist but in limited amounts. The increased pressure in these areas may seriously and permanently degrade the soil and vegetation.

R1. ROCKY LAND

The rocky land exists in intimate association with the sand dunes and occurs primarily north of the Senegal River. Slopes may range from very steep to gentle. It is an area of bedrock exposure. Where the rocky land interfaces with the dunes, thin sheet sand deposits may overlie the rock. Drainageways are incised into the area. Some xerophytic vegetation may grow along the stream channels. By and large, the area is unsuited for intensive grazing because of low rainfall amounts, severe wind and water erosion and very thin or absent soil to support vegetation.

A. AGRICULTURAL LAND

The agricultural land exists mostly along the Senegal River and along the coast line. These are areas with more moisture available for crop production. The soils are also more suited in these areas. They have loam or finer textures, except along the river, and hold moisture for longer periods. They are less severely weathered and more naturally fertile.

A1. Irrigated Agriculture: This is an area near the town of Rosso on the Senegal River delta. Several irrigation projects have been constructed in Senegal and Mauritania. They produce mostly rice and sugar cane. Fresh water is available seasonally from the river and from Lac de Guiers.

A2. Flood Recession Agriculture: This is an area along the Senegal River and includes the Gorgol Region. During the rainy season, the river floods the alluvial areas around it. When the flood waters recede, the soils are satisfied to maximum water storage capacity. As soon as possible, the land is worked and small grains planted to take advantage of the stored soil moisture to produce a crop. During dry years, when flood stages are low, a less than average amount of flooding may occur. Crops are not planted where the land has not flooded and consequently, production of food will be severely reduced.

A3. Rainfed Agriculture: This land use catagory was delineated in the southeastern portion of the study area along the coast. With the possible exception of commercial ground nut production, crops are grown in small patches around villages. This subsistance production consists mostly of millet, sorghum and some maize. Some livestock grazing is also associated with this land use area although it is not as extensive as in other areas.

G. GRAZING LAND

The majority of the area south of the Senegal River is classified as grazing land. Most of the grazing is nomadic rather than sedentary, with the livestock moved to follow vegetation as precipitation and available moisture dictate.

G1. Mixed Savanna: This is an area of savanna with tall grasses and brush such as Acacia spp. and Balanites. Along drainageways, deciduous forests may exist. Semi-deciduous forests exist in the transition zones between savanna and forest. The soils in this area are moderately fine textured and can support vegetation even during periods of insufficient rainfall but not for extended periods. This is most likely, a durable, drought tolerant range.

G2. Tall Grass Savanna: This is a tall grass savanna with scattered xerophytic forbs and shrubs. Rainfall is somewhat limited even in normal years. This grazing land is acceptable during most years but a moisture deficiency would be seen quite early in dry years.

G3. Grass Savanna: This is an area with mostly short and medium grasses and widely scattered xerophytic forb and shrub species. This area is sensitive to drought conditions. During dry periods, livestock which might normally graze in area D2 could be grazed in this area. This increased pressure on an already fragile landscape could have serious and permanent effects. Even during normal rainfall years, this is not a highly productive area.

G4. Submarginal Grazing Land: This is a very dry area with sparse vegetation. Grazing is limited even during normal rainfall years.

G5. Marginal Grazing Lands: This area is composed mainly of deeply incised drainages in the southeastern part of the study area. Phreatophytic vegetation may be found along alluvial areas next to

stream channels. Although the vegetation may be dense, only a small percentage of the area is of this type. The remainder, and largest portion, of the area is steeply sloping, extremely eroded land with little, xerophytic vegetation produced. This area cannot support much grazing activity.

M. Coastal Marshes: Two coastal marsh areas exist. They are subject to salt water intrusion, are salty and very wet. These areas have limited potential for agriculture.

W. Open Water: These are bodies of fresh water and are largely a result of flood water recession. During dry years they may be small and larger and more persistant during normal or above normal rainfall years.

Interpretations and Discussion

Several aspects of desertification could be observed on the Landsat imagery used in this study. The data were from 1972, 1973, 1976 and 1977. All black and white imagery were in Band 5, from 0.60 to 0.70 micrometer wavelength portion of the visible spectrum. The false color composites cover wavelengths from 0.50 to 1.10 micrometer, part of the visible and near infrared portions of the spectrum. Advantage was taken of the temporal nature of the Landsat data to demonstrate seasonal as well as annual variations in vegetation and surface water resources. Although Band 7 is commonly used in water resource evaluation, the data were not available at the time of interpretation. Further analysis of Band 7 should be incorporated into any additional investigations of water resources distributions as indicators of desertification. Of the black and white bands of Landsat data, the Band 5 offers an advantage in vegetation analysis where the soils are light colored and the vegetation is sparse.

Figure 1 shows the locations of all the other figures which follow. This was prepared to establish the spatial distribution of the features within the study area which are discussed. Table 3 lists the figure number, date, Landsat scene identification number and scale of figures 2 through 9.

Figures 2a, 2b and 2c represent changes in a very fragile seasonal grazing area in a region in and around Rosso and in southern Mauritania, and in the Lac de R'Kiz area. The lines running from east to west across the 1972 imagery (Fig. 2a) are skips in the sensor scan

Fig. 1. Mosaic of the study area showing spatial distribution and relative location of scenes presented in Figures 2 through 9. Scale approximately 1:4,000,000.

Table 5. Pertinent Landsat scene information used in Figures 2 through 9.

Fig. No.	Date	Scene ID No.	Scale	Type of Imagery
2a	5 Nov. 1972	1105-10562	1:500,000	Band 5
2b	15 Feb. 1976	2389-10413	1:500,000	Band 5
2c	6 Nov. 1977	6019-10160	1:500,000	Band 5
3a	5 Nov. 1972	1105-10565	1:500,000	Band 5
3b	15 Feb. 1976	2389-10420	1:500,000	Band 5
3c	6 Nov. 1977	6019-10162	1:500,000	Band 5
4a	5 Nov. 1972	1105-10505	1:500,000	Band 5
4b	15 Feb. 1976	2389-10420	1:500,000	Band 5
4c	6 Nov. 1977	6019-10162	1:500,000	Band 5
5a	9 Mar. 1973	6053-10033	1:250,000	False Color
5b	10 Dec. 1977	1229-10454	1:250,000	Composite (FCC)
6a	10 Dec. 1972	1140-10511	1:500,000	Band 5
6b	5 Nov. 1977	6018-10104	1:500,000	Band 5
7a	9 Mar. 1973	1229-10454	1:250,000	FCC
7b	10 Dec. 1977	6053-10033	1:250,000	FCC
8a	3 Nov. 1972	1103-10452	1:250,000	FCC
8b	10 Dec. 1977	6053-10033	1:250,000	FCC
9a	10 Dec. 1972	1140-10511	1:500,000	Band 5
9b	5 Nov. 1977	6018-10104	1:500,000	Band 5

lines. In addition, cloud cover (white areas) is apparent in the southwest corner and in the southeast corner, over the Senegal River.

There are several features of interest in this set of temporal images. Normal rainfall in Podor is reported as 327.4 mm per year (FAO, 1977b). In 1972, 579 mm was reported with 558 mm of that total reported in July (Appendix A), the remaining 21 mm was distributed through the rest of the wet season. The Landsat overpass occurred on 5 November 1972. In 1976, 258 mm was reported; however, it was more uniformly distributed through the season. In 1977, only 34 mm fell, mostly in August.

The area indicated by and surrounding "A" in Figures 2a, 2b and 2c illustrates the influence of rainfall on the growth of vegetation in interdune areas. In 1976 (Fig. 2b) the mottled dark pattern is associated with vegetative growth which can be used for seasonal grazing. In 1972 (Fig. 2a) and 1977 (Fig. 2c) most of the dark mottles are absent due to limited rainfall. This is interpreted to mean less vegetative growth, probably insufficient to support the usual amount of grazing. The light areas represent active, barren, moving sand dunes. A decrease in grazing potential of this magnitude would have to be counterbalanced by increased pressure in other areas which could result in overgrazing and denudation of already stressed areas. Lac de R'Kiz appears larger in 1972 than the other years probably in response to the high rainfall in July of that year. The area is relatively constant, however, which may indicate that the lake is fed from ground water sources in addition to seasonal flooding from the Senegal River.

2a. 5 November 1972. Scanner malfunction is noted by horizontal lines. Clouds are in evidence in south and west part of scene.

Fig. 2. Scenes exhibiting a climatic-dependent, seasonal grazing region. The influence of short- and long-term climatic effects are portrayed. Temporal changes can be noted by comparing the same region in different years. A) interdune area where ephemeral vegetation can support some livestock grazing in normal years. Dark tones indicate vegetation while lighter tones are non-vegetated or barren dune areas, B) seasonality of flooding is exemplified by lake expansion or contraction, C) long-term dune encroachment on cropping practices, D) example of variable amount of water in main Senegal River channel.

2b. 15 February 1976.

Fig. 2. Continued.

2c. 6 November 1977

Fig. 2. Continued.

In 1972 and 1977, both dry years in the Sahel, the small white patch east of "B" in Figures 2a and 2c indicates a dried water impoundment. In 1976 this area is dark indicating more moisture and vegetation. A small area east of "C" demonstrates sand dune migration and encroachment onto arable alluvial land. From 1972 to 1977 the sands appear to have moved approximately 2 km.

The main channel of the Senegal River is south of "D" in Figures 2b and 2c. It is covered by clouds in 2a. In 1976 the channel is clearly defined as a dark water body. In 1977 the channel is less obvious indicating an absence of water. Annual flood stage is very important to flood rescession agriculture. Production may be limited during dry years like 1972 and 1977.

The features at A, B and D are short term influences of drought conditions. At point C, the effects of desertification are of a long term nature.

Figures 3a, 3b and 3c are north of Saint Louis, Senegal and cover a portion of the Senegal River delta. The normal rainfall there is 338.8 mm (FAO, 1977b). The area received 164 mm in 1972, 196 mm in 1976 and 31 mm in 1977 (Appendix A). The most apparent difference is immediately east of "E", the main channel of the Senegal River. It is vague in 1972 and 1977 (Figs. 2a and 2c) presumably because of low flow. In 1976 it is an obvious dark line with water.

East of "F" in 1972 is an area of apparent inundation. This does not show water in 1976. The 1976 imagery is from 15 February, whereas

3a. 5 November 1977

Fig. 3. Seasonal flooding at mouth of Senegal River is shown. Dark areas are wet, intermediate tones, relative to their position in the flood basin, are either moist with or without vegetation or are vegetation, and light tones are areas devoid of vegetation. E) variable amounts of water in channel, F) an area of seasonal flooding, indications of seasonal precipitation are shown by extent of flooding.

3b. 15 February 1976

Fig. 3. Continued.

3c. 5 November 1972

Fig. 3. Continued.

the 1972 imagery is from 5 November. February is an extremely dry part of the year and evapotranspiration demands may have dried this area. It was very indistinct on 6 November 1977, a very dry year. The lake east of the Senegal River at "E" is larger in 1972 than 1976 or 1977, which are similar. This may be caused by time of observation and climate together. The evidences in Figures 3a, 3b and 3c are short term effects of insufficient precipitation.

The channel associated with Vallée du Ferlo reflects short term effects of drought (Fig. 4a, 4b and 4c). The higher flows of water can be seen south of "G". There is a dark, well defined channel in 1972 and 1976 but in 1977 it shows only dark gray areas of vegetation, not water. The small tributary immediately west of "G" shows a similar pattern.

The Gorgol is a significant area of flood recession agricultural production. Normal precipitation at Matam is 529.9 mm per year (FAO, 1977b). In 1973 the area received 220 mm and in 1977, 17 mm of rainfall (Appendix A). Figure 5a illustrates the conditions on 9 March 1973. No significant precipitation had been received for the preceding 6 months. The area south of "J" appears dry and lacking vegetation. The red around "K" represents some actively growing vegetation along the Senegal River. This area would normally be flooded for long periods of time (Personal communication, Bill Pearson, AID/AFR/SFWA). On 10 December 1977 (Fig. 5b) only a small amount of water can be seen as bright blue areas south of "J". This is an unusually small amount of flooding and it will limit the area planted to crops.

4a. 5 November 1972

4b. 15 February 1976

4c. 6 November 1977

Fig. 4. Indicators of seasonal precipitation are evidenced by the amount of water in intermittent and unclassified streams. G) junction of an unclassified drainageway and a seasonal stream.

5a. 9 March 1973

5b. 10 December 1973

Fig. 5. Extent of annual flooding in the Gorgol region is shown. J) flood water distributions (blue) are shown, K) vegetation patterns are indicated in flood plain as season progresses (red tones are areas of actively growing vegetation).

The influence of several successive dry years on flood recession vegetative growth can be seen in Figures 6a and 6b, 1972 and 1977, respectively. In 1972, between the two channels of the Senegal River, "T", the dark area, partially covered with white clouds, represents past flood vegetative growth which is dependent on soil moisture supplied by previous floods. In 1977, the same area shows no growth. This is most likely due to the below normal precipiation and flooding in the intervening years.

At the point indicated by "S" in 1972 the sand dunes interface with the flood plain of the Senegal River as indicated by the white to dark gray zone northwest of the letter. In 1977, a finger of sand, north of "S", has encroached approximately 5 km upon the arable alluvial land. Long term desertification is therefore evident at this location.

Figures 7a and 7b show an area in the southeast portion of the Gorgol. Fig. 7a is a 9 March 1973 scene and it shows normal patterns during the dry season. Some red along the Senegal River indicates growth of vegetation. Figure 7b is a 10 December 1977 scene. The large patch surrounding "R" is a burn pattern. Burning practices are unusual for December in this area (personal communication, Bill Pearson, AID/AFR/SFWA). This could most probably result from burning of dry vegetation, a definite indicator of dry conditions. Some water bodies (bright blue color) are seen near the Senegal River. This is typical at this time of year.

Figures 8a (1972) and 8b (1977) show Landsat coverage of the influence of the Senegal and Faléme Rivers southeast of Bakel, Senegal. The red

Fig. 6a. 10 December 1972. Note cloud coverage in west central part of scene.

Fig. 6. Example of long and short term desertification indicators are presented. S) long term indication of desert encroachment is shown by the recession of floodplain vegetation, T) short-term indication of a drier year is evidenced by the dependence of agriculture on the extent of flooding.

Fig. 6b. 5 November 1977.

Fig. 6. Continued.

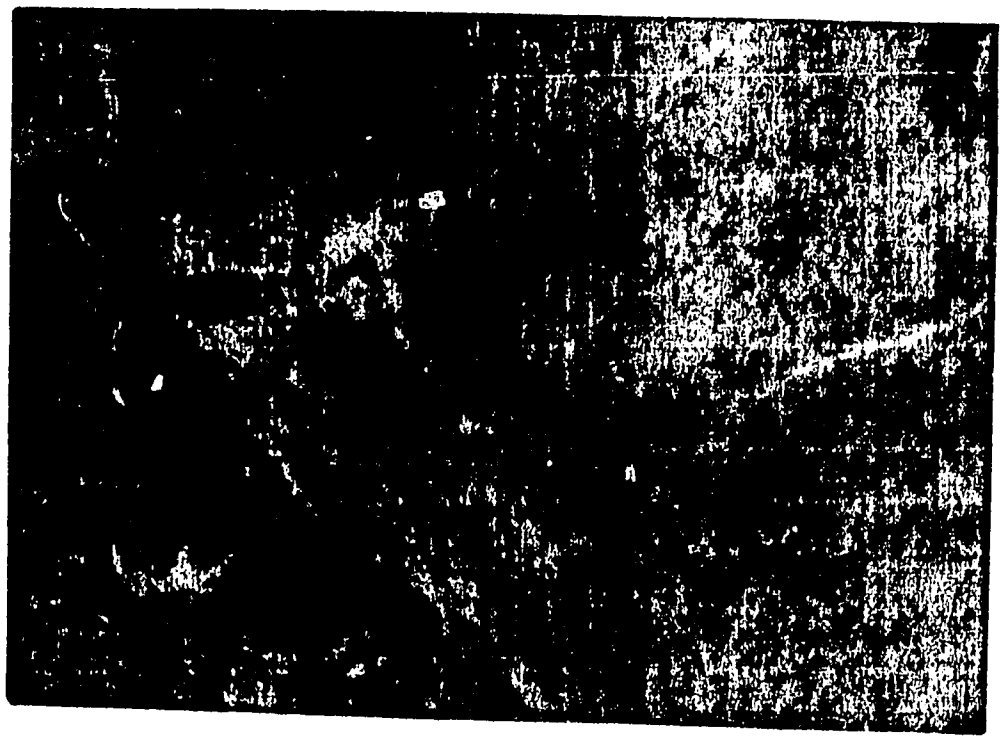

Fig. 7a. 9 March 1973.

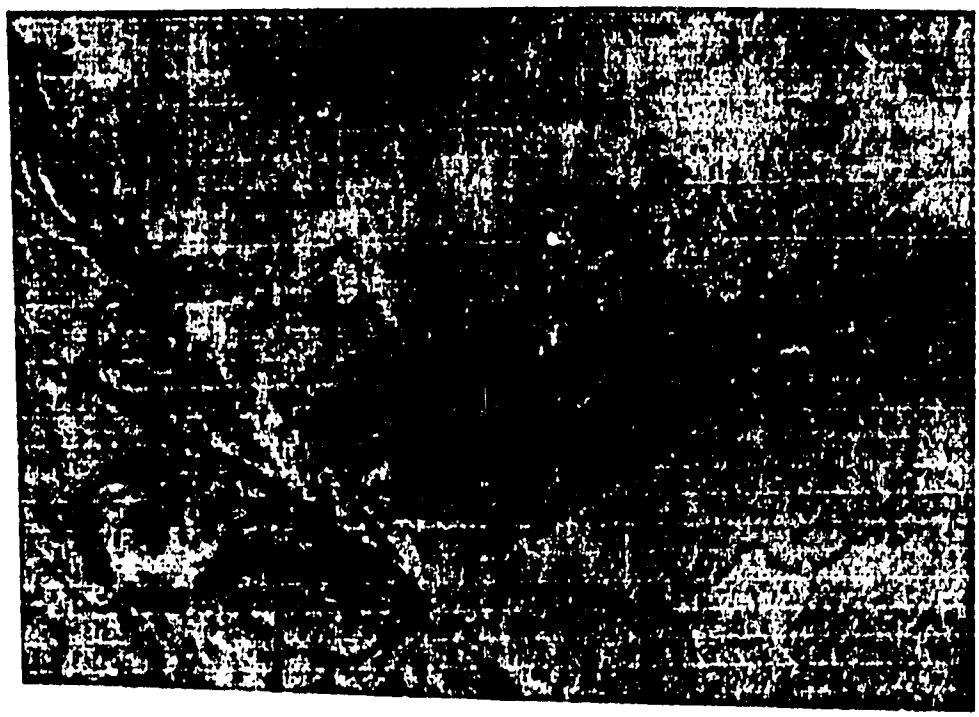

Fig. 7b. 10 December 1977.

Fig. 7. Influence of man on imagery recorded patterns is exhibited. The burn pattern (R) in the Gorgol Region appeared after a series of dry years.

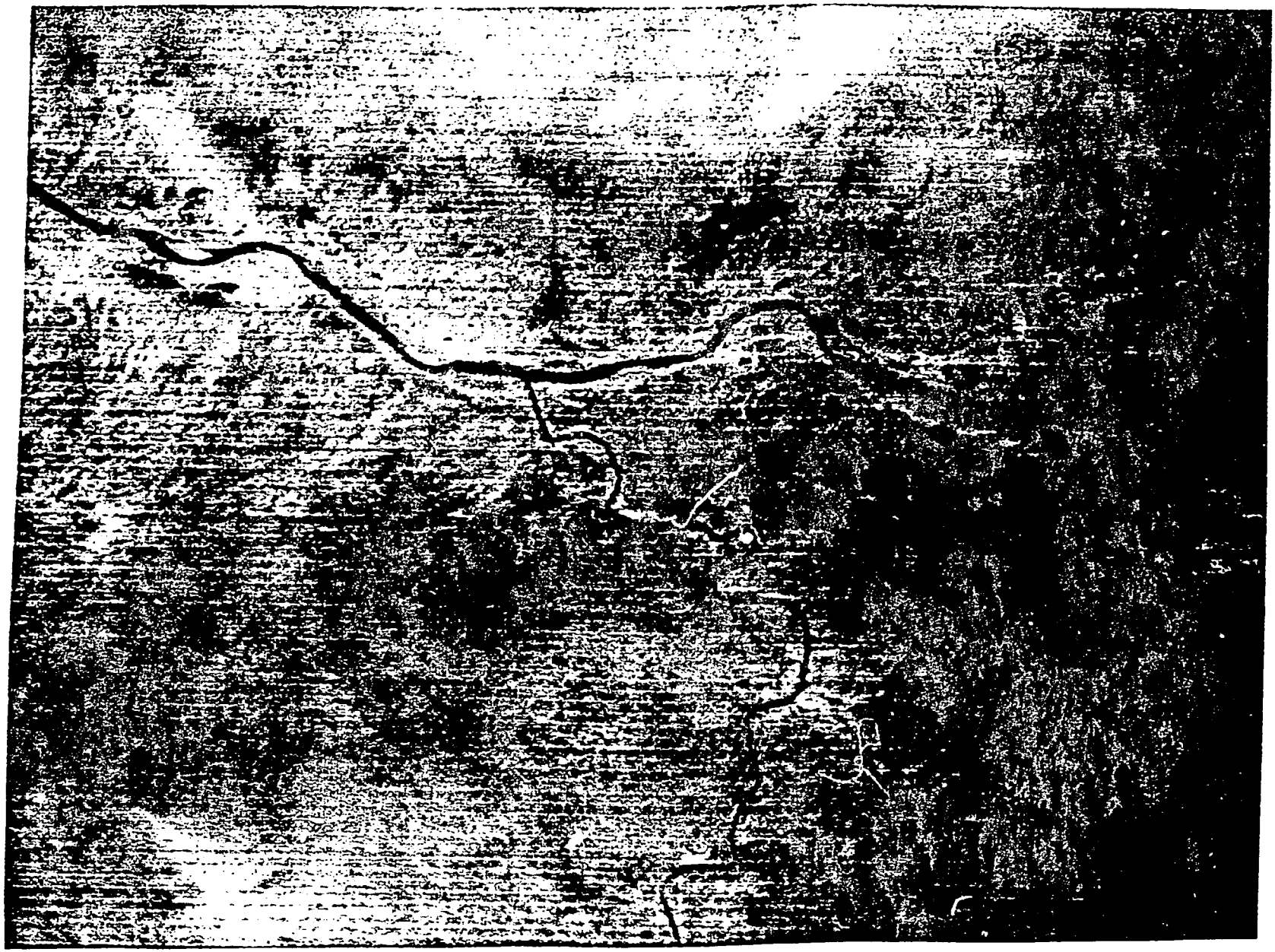

Fig. 8a. 3 November 1972.

Fig. 8. The effects of changing landscape patterns are shown. (X) what appears to be a new burn area has appeared between 1972 and 1977, (Y) growing vegetation in a stream channel is contrasted in two years, (Z) patterns indicative of vegetation and/or a change in vegetative structure are shown to be receding from the Senegal River floodplain.

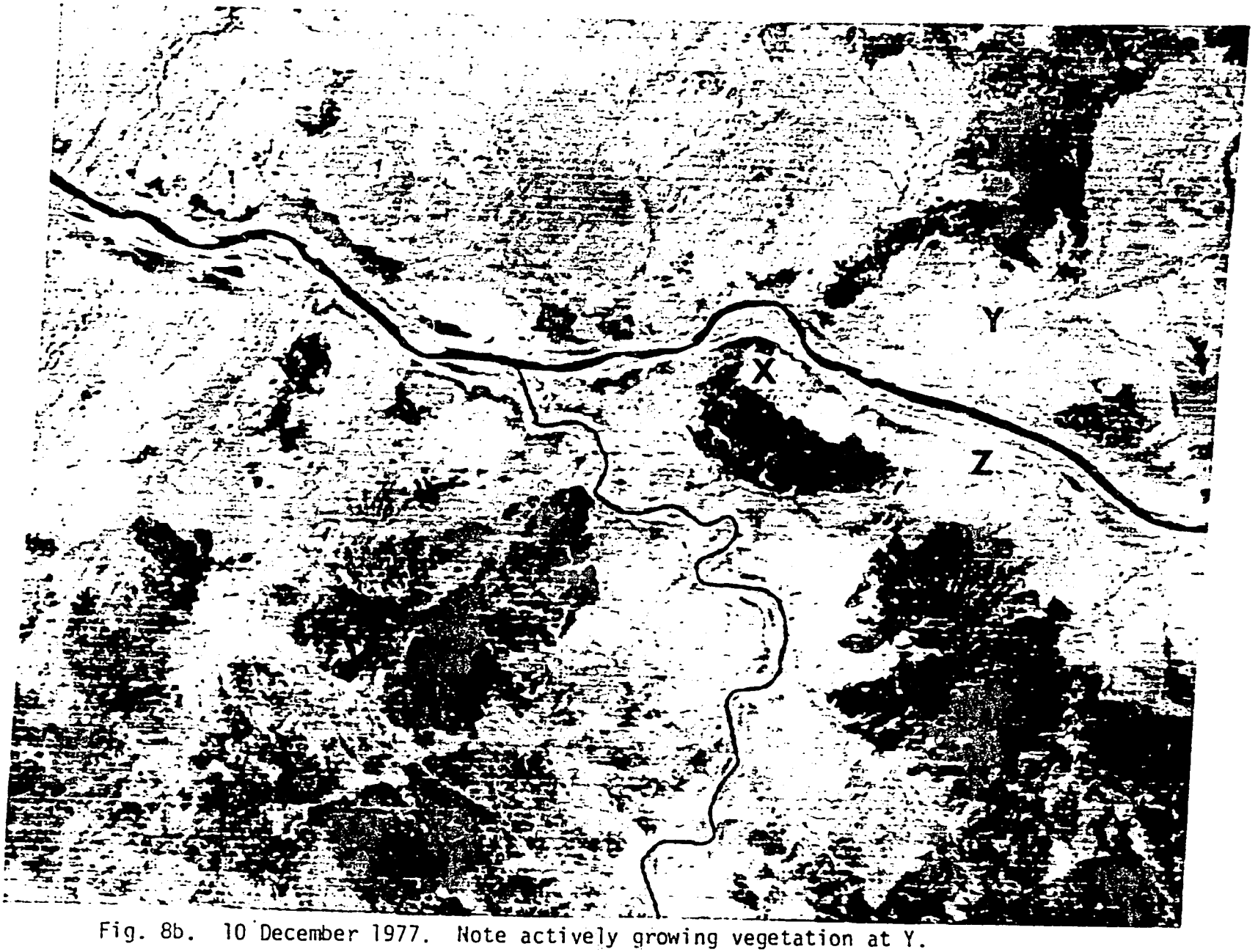

Fig. 8b. 10 December 1977. Note actively growing vegetation at Y.

Fig. 8. Continued.

areas on the 1977 data, as marked by "V" are active growing vegetation. They contrast sharply with the dry, surrounding landscape. The same color indicates vegetation growing along most drainageways. In 1977, a large, green pattern exists south of "X". This may be a burn pattern but positive identification cannot be made without ground verification. The burn area did not exist in 1972 (south of "X" on Figure 8a). A similar situation exists south of "Z". In 1972, the area was extensive but had shrunk considerably in 1977. West of "Y" in 1972 a channel is clearly seen by the reddish color indicative of vegetative growth. In 1977, a drier year, the same channel is apparently devoid of vegetation.

Figures 9a (1972) and 9b (1977) illustrate a long term effect of desertification. The area around "H" in each figure is an area of salt accumulation or salinization. This has been recognized as an indicator of increasing aridity by pedologists (Dregne, 1976). The speckled pattern is barely seen in 1972 but is evident in 1977. Land so affected is nearly permanently removed from production, its potential reduced to zero.

Fig. 9a. 10 December 1972

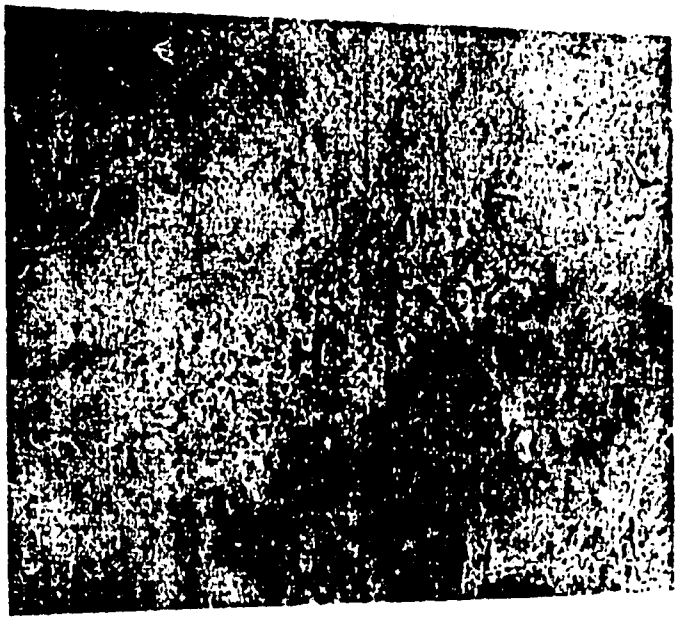

Fig. 9b. 5 November 1977

Fig. 9. A long term effect of desertification is shown in area of aridic soils (H) salinization patterns, shown as speckled areas, as they change with time.

SUMMARY

Several indicators of short, intermediate and long term desertification effects have been illustrated and discussed. In general, the distribution of these indicators throughout the study area follows the pattern of soils as delineated on the Soil Resources Map. This is expectable since soils are known to reflect climatic and vegetation zonation. In addition, soils are responsive indicators of environmental conditions from both long and short time spans. The long term climate determines the major zonation of soils which can be rapidly modified by short term climatic and man-induced environmental changes.

The Entisols are very fragile soils as seen in Figures 2a, 2b and 2c. The response of an arid to semi-arid transitional ecotone might be rapidly reflected in the vegetation associated with the Entisols.

If attention is focused on intermediate time changes, the region of Aridisols becomes significant. This is also a fragile area but more permanent changes may be detected. Whereas the Entisols (viz. dune areas) vary or shift annually, a recessive change in the Aridisols will remain as marks on the landscape. Erosion, resulting from overgrazing, or salinization (Figure 9a and 9b) are indicators which are expressed with relative rapidity in the Aridisol areas.

As the soils become more weathered and more fully developed, they also become more resistant to the changes induced by drought and desertification. There are areas with higher rainfall and more dense vegetation. Changes are more subtle. The changes which occur reflect

more long term influences. However, short term and even annual conditions may be superimposed over the long term responses. Even in areas of Entisols, long term responses or trends may be seen, e.g. sand dune migration onto arable lands (Figures 6a and 6b).

Within the study area, the soil orders occur in subparallel east to west zones. The Entisols occur furthest north. Progressively southward the zones are Aridisols, Inceptisols, Alfisols, Vertisols and Oxisols. Each of these orders responds differently, on a macro scale, to desertification processes. The relative degree of expression is presented schematically in Figure 10. If short term effects were of primary interest, the Entisols would express them most rapidly and clearly. Long term indicators would be less obvious. Conversely, the Oxisols would reflect few short term responses and mostly severe long term effects.

These changes have been examined on Landsat imagery and illustrative example areas discussed. With ground observation and data collection, the response of soil mapping units to desertification could be approached in a more quantitative and detailed manner when mapping and interpretating. Indicators other than those visualized and discussed in this report are probably recorded in the Landsat data when observing other dates and spectral bands. Landsat data can be an effective tool in monitoring the status of arid and semi-arid land revealing short, intermediate and long term effects of desertification.

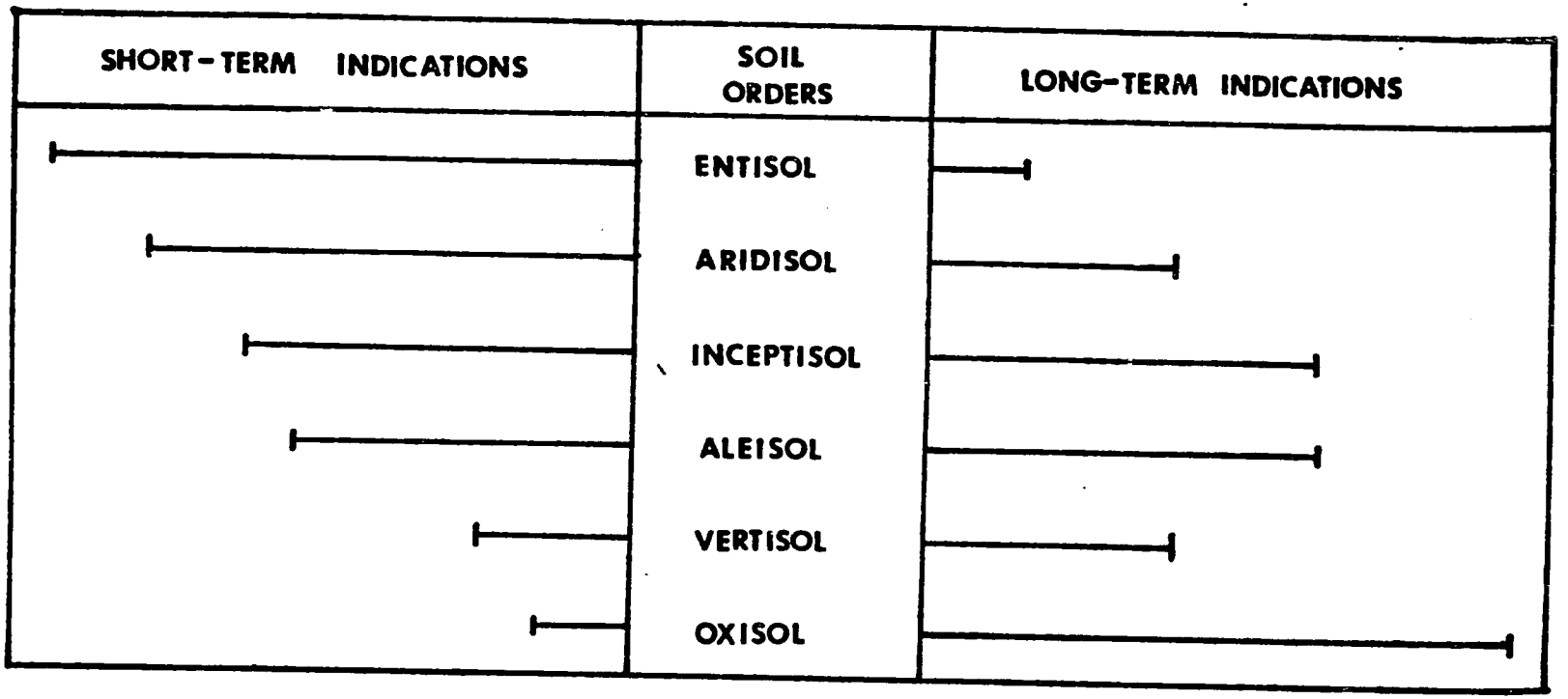

Fig. 10. Relative degree of expression of desertification effects by soil orders in the study area. Longer lines indicate greater degree of expression.

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APPENDIX A

Climatic Data

LEGEND

Country	Station
M = Mauritania	1 = Noaukchott
	2 = Rosso
	3 = Boutilimit
	4 = Kiffa
	5 = Aioun El Altrouss
S = Senegal	1 = St. Louis
	2 = Diourbel
	3 = Kaolack
	4 = Podor
	5 = Linguere
	6 = Matam

COUNTRY	STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE TEMP
S	1	1972	21.2	21.8	22.0	21.4	22.6	25.3	26.2	27.8	28.0	28.0	0.0*	0.0	24.4
S	1	1973	0.0	0.0	23.0	25.0	25.9	24.3	27.1	28.3	27.9	26.9	26.9	22.7	25.7
S	1	1974	0.0	23.3	23.6	22.3	22.4	24.5	26.7	27.4	0.0	27.2	24.0	22.9	24.4
S	1	1975	22.9	22.5	22.0	22.3	32.3	25.2	27.9	28.0	27.7	27.9	24.2	22.4	25.4
S	1	1976	20.5	0.0	22.3	22.0	26.1	25.0	27.0	28.4	28.6	27.2	25.7	20.7	24.8
S	1	1977	21.4	27.3	24.9	23.2	22.6	25.7	27.1	27.5	0.0	0.0	0.0	0.0	25.0
S	2	1972	23.4	25.1	26.7	26.7	28.3	29.1	29.3	28.4	28.4	0.0	0.0	0.0	27.3
S	2	1973	0.0	0.0	27.0	28.5	26.6	30.5	28.7	28.0	28.6	29.9	27.9	24.0	28.2
S	2	1974	23.8	0.0	25.5	26.0	28.1	28.5	28.1	27.5	27.9	28.2	25.8	24.2	26.7
S	2	1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S	2	1976	22.7	0.0	26.5	27.7	27.1	29.0	28.7	28.2	28.0	27.8	27.0	23.8	27.0
S	2	1977	24.2	26.2	28.5	28.1	27.8	29.9	28.9	28.4	0.0	0.0	0.0	0.0	27.7
S	3	1972	24.2	25.3	27.4	27.8	29.2	28.7	29.0	28.0	28.1	0.0	0.0	0.0	27.6
S	3	1973	0.0	0.0	26.3	29.6	28.5	30.4	28.3	27.6	28.3	0.0	28.3	24.6	28.2
S	3	1974	24.5	26.4	27.1	28.0	29.0	29.6	28.0	27.5	27.6	0.0	26.8	25.2	27.2
S	3	1975	25.3	26.4	27.2	29.1	29.8	29.2	27.3	27.9	26.9	28.7	26.3	25.4	27.4
S	3	1976	23.2	0.0	27.9	29.4	28.4	28.9	28.5	28.2	28.1	28.3	27.9	24.9	27.6
S	3	1977	25.7	27.6	29.8	29.4	29.3	29.6	29.1	28.6	0.0	0.0	0.0	0.0	28.7
S	4	1972	23.1	24.5	27.3	28.7	30.7	32.1	31.0	31.4	32.2	0.0	0.0	0.0	29.0
S	4	1973	0.0	0.0	23.3	30.9	33.5	33.4	31.0	30.4	31.2	31.1	28.2	22.3	30.0
S	4	1974	22.3	0.0	24.9	27.6	31.6	30.6	29.6	29.3	30.3	30.0	26.7	23.6	28.4
S	4	1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S	4	1976	21.4	0.0	26.4	30.5	29.9	32.0	30.9	30.2	30.8	30.6	27.8	23.3	28.5
S	4	1977	24.1	25.8	29.6	29.8	31.3	32.3	31.5	30.5	0.0	0.0	0.0	0.0	29.4
S	5	1972	24.8	25.6	28.2	28.6	31.2	31.1	31.2	29.8	30.2	31.2	0.0	0.0	29.2
S	5	1973	0.0	0.0	25.3	31.4	31.7	32.7	30.2	29.0	29.0	30.8	28.6	23.9	29.7
S	5	1974	23.6	25.7	26.5	28.5	30.9	0.0	29.3	28.0	23.4	0.0	27.8	25.5	27.4
S	5	1975	25.1	25.7	27.7	29.6	31.1	31.4	0.0	28.3	27.7	29.4	26.6	26.1	28.2
S	5	1976	22.7	0.0	27.8	30.0	30.2	30.9	30.0	29.0	26.7	29.0	29.0	24.4	28.3
S	5	1977	25.3	27.6	30.7	30.3	31.3	31.5	30.2	29.4	0.0	0.0	0.0	0.0	29.5
S	6	1972	24.3	26.4	29.5	32.5	34.3	0.0	33.6	0.0	31.5	32.4	0.0	0.0	30.6
S	6	1973	0.0	0.0	30.4	33.5	0.0	35.0	32.2	29.2	31.0	31.9	0.0	23.8	30.7
S	6	1974	23.6	24.1	28.0	31.4	0.0	34.7	30.7	28.6	29.4	29.2	27.5	24.6	28.3
S	6	1975	24.2	26.0	28.9	31.7	34.3	34.2	29.1	29.2	29.2	30.5	26.6	26.1	29.2
S	6	1976	22.4	0.0	28.8	33.2	33.6	33.3	31.8	29.6	30.0	30.6	25.0	24.6	29.6
S	6	1977	25.3	27.3	30.0	0.0	31.1	34.6	29.6	0.0	0.0	0.0	0.0	0.0	28.6

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TEMPERATURE STATISTICS

COUNTRY	STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE TEMP
M	1	1972	20.8	21.4	21.9	22.9	23.0	26.0	25.7	22.7	28.1	28.2	0.0*	0.0	24.1
M	1	1973	0.0	0.0	23.5	24.1	26.2	28.2	26.3	27.9	28.8	27.9	25.3	19.7	25.8
M	1	1974	20.8	21.1	20.8	21.6	21.1	24.7	25.9	0.0	29.2	27.5	24.0	22.5	23.6
M	1	1975	22.0	21.9	0.0	22.1	23.8	26.9	26.3	28.2	28.5	0.0	23.9	22.0	24.6
M	1	1976	19.9	0.0	22.0	0.0	22.7	25.9	28.1	29.1	29.8	27.7	25.3	19.7	25.0
M	1	1977	21.4	23.7	26.5	25.2	23.8	27.4	26.8	26.8	0.0	0.0	0.0	0.0	24.9
M	2	1972	23.9	24.2	25.6	26.2	27.5	29.4	26.6	0.0	30.4	0.0	0.0	0.0	27.0
M	2	1973	0.0	0.0	26.6	0.0	29.4	30.9	29.1	29.0	0.0	29.7	27.5	21.9	28.0
M	2	1974	23.5	0.0	0.0	25.1	27.9	28.3	28.2	28.3	29.5	29.2	25.9	23.7	26.4
M	2	1975	23.5	24.5	0.0	26.1	27.9	29.4	27.7	28.9	28.4	29.8	25.4	24.4	26.9
M	2	1976	21.6	0.0	25.5	27.5	28.4	29.1	25.0	29.5	29.6	29.2	27.0	22.4	26.6
M	2	1977	23.6	25.6	28.6	27.1	27.7	29.7	0.0	28.9	0.0	0.0	0.0	0.0	27.3
M	3	1972	23.9	23.8	25.3	27.5	0.0	32.3	30.7	31.6	32.2	0.0	0.0	0.0	28.5
M	3	1973	0.0	0.0	27.8	30.4	34.1	34.0	30.6	30.4	31.6	31.8	28.1	20.8	30.0
M	3	1974	21.5	21.8	25.5	0.0	32.2	32.4	31.8	29.2	0.0	30.5	27.7	22.9	27.3
M	3	1975	0.0	25.0	0.0	27.2	30.5	32.6	28.6	29.8	29.5	31.8	26.4	24.2	28.6
M	3	1976	23.4	0.0	25.7	29.7	0.0	0.0	33.0	31.7	25.0	30.4	0.0	21.6	27.2
M	3	1977	0.0	0.0	0.0	0.0	0.0	0.0	34.2	30.2	0.0	0.0	0.0	0.0	32.2
M	4	1972	22.8	24.5	26.3	31.4	0.0	34.9	28.0	32.5	32.6	33.4	0.0	0.0	29.4
M	4	1973	0.0	0.0	29.1	32.7	36.6	34.8	33.6	31.0	32.4	31.3	28.6	23.7	31.1
M	4	1974	0.0	23.4	26.0	30.0	35.0	35.9	31.8	30.0	31.0	32.0	32.0	27.5	30.4
M	4	1975	22.7	24.6	0.0	31.6	34.3	35.3	30.8	30.4	31.2	31.6	25.5	24.9	29.4
M	4	1976	0.0	0.0	0.0	0.0	33.6	35.1	0.0	30.8	0.0	30.3	21.4	23.3	29.1
M	4	1977	23.6	20.1	29.7	32.9	34.7	0.0	33.7	0.0	0.0	0.0	0.0	0.0	29.1
M	5	1972	22.2	24.3	27.9	30.9	32.9	34.6	34.0	32.4	33.1	0.0	0.0	0.0	30.3
M	5	1973	0.0	0.0	26.6	0.0	36.4	0.0	0.0	30.5	32.5	31.5	26.2	19.5	29.6
M	5	1974	20.2	0.0	25.8	30.3	35.0	35.5	31.4	29.9	30.9	30.3	27.3	22.6	29.0
M	5	1975	21.8	24.1	0.0	30.7	33.5	34.8	30.3	29.7	30.6	31.5	24.6	24.7	28.8
M	5	1976	19.6	0.0	25.4	30.6	32.6	30.3	33.3	34.0	31.2	30.9	25.8	22.9	28.8
M	5	1977	23.5	24.2	29.0	32.0	34.3	36.0	32.8	32.2	0.0	0.0	0.0	0.0	30.5

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PRECIPITATION STATISTICS

COUNTRY	STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL PRECIP
5	1	1972	0.0	0.0	5.0	0.0	0.0	22.0	10.0	35.0	88.0	6.0	-9.0	-9.0	164.0
5	1	1973	-9.0	-9.0	0.0	0.0	0.0	3.0	14.0	119.0	47.0	0.0	6.0	0.0	189.0
5	1	1974	0.0	0.0	1.0	0.0	0.0	0.0	25.0	80.0	79.0	12.0	0.0	0.0	197.0
5	1	1975	0.0	0.0	0.0	0.0	0.0	0.0	207.0	93.0	75.0	39.0	0.0	0.0	414.0
5	1	1976	0.0	-9.0	0.0	0.0	0.0	0.0	8.0	52.0	123.0	3.0	0.0	10.0	196.0
5	1	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.0	-9.0	-9.0	-9.0	-9.0	31.0
5	2	1972	2.0	0.0	0.0	0.0	0.0	43.0	58.0	149.0	122.0	-9.0	-9.0	-9.0	374.0
5	2	1973	-9.0	-9.0	0.0	0.0	0.0	4.0	113.0	158.0	58.0	0.0	0.0	0.0	333.0
5	2	1974	0.0	-9.0	0.0	0.0	0.0	5.0	166.0	303.0	117.0	0.0	0.0	0.0	598.0
5	2	1975	-9.0	-9.0	-9.0	-9.0	-9.0	-9.0	-9.0	0.0	-9.0	-9.0	-9.0	-9.0	-9.0
5	2	1976	0.0	-9.0	0.0	0.0	0.0	2.0	101.0	127.0	174.0	88.0	0.0	4.0	496.0
5	2	1977	0.0	0.0	0.0	0.0	0.0	7.0	98.0	119.0	-9.0	-9.0	-9.0	-9.0	224.0
5	3	1972	2.0	0.0	0.0	0.0	52.0	16.0	164.0	168.0	0.0	-9.0	-9.0	-9.0	452.0
5	3	1973	-9.0	-9.0	0.0	0.0	0.0	1.0	168.0	181.0	80.0	12.0	0.0	0.0	440.0
5	3	1974	0.0	0.0	0.0	0.0	1.0	4.0	126.0	288.0	117.0	0.0	-9.0	0.0	536.0
5	3	1975	0.0	0.0	0.0	0.0	0.0	1.0	223.0	127.0	158.0	14.0	0.0	0.0	523.0
5	3	1976	1.0	0.0	2.0	0.0	26.0	18.0	108.0	92.0	138.0	76.0	0.0	3.0	474.0
5	3	1977	0.0	0.0	0.0	0.0	0.0	14.0	103.0	154.0	-9.0	-9.0	-9.0	0.0	271.0
5	4	1972	0.0	0.0	0.0	0.0	4.0	16.0	554.0	2.0	0.0	-9.0	-9.0	-9.0	576.0
5	4	1973	-9.0	-9.0	0.0	0.0	0.0	9.0	34.0	87.0	20.0	0.0	0.0	0.0	152.0
5	4	1974	0.0	-9.0	0.0	0.0	0.0	0.0	43.0	74.0	32.0	1.0	0.0	0.0	150.0
5	4	1975	-9.0	-9.0	-9.0	-9.0	-9.0	0.0	-9.0	-9.0	-9.0	-9.0	-9.0	-9.0	-9.0
5	4	1976	1.0	-9.0	7.0	0.0	0.0	10.0	53.0	115.0	94.0	3.0	0.0	10.0	293.0
5	4	1977	0.0	0.0	0.0	0.0	0.0	0.0	1.0	33.0	-9.0	-9.0	-9.0	-9.0	34.0
5	5	1972	7.0	0.0	0.0	0.0	0.0	46.0	59.0	73.0	45.0	14.0	-9.0	-9.0	245.0
5	5	1973	-9.0	-9.0	0.0	0.0	0.0	0.0	50.0	121.0	85.0	0.0	0.0	0.0	256.0
5	5	1974	0.0	0.0	0.0	0.0	0.0	0.0	45.0	173.0	80.0	-9.0	0.0	0.0	304.0
5	5	1975	0.0	0.0	0.0	0.0	2.0	18.0	-9.0	130.0	73.0	-9.0	0.0	0.0	223.0
5	5	1976	2.0	-9.0	0.0	0.0	0.0	0.0	75.0	134.0	93.0	52.0	1.0	5.0	365.0
5	5	1977	0.0	0.0	0.0	0.0	0.0	5.0	55.0	192.0	-9.0	-9.0	-9.0	-9.0	262.0
5	6	1972	2.0	0.0	0.0	0.0	0.0	-9.0	11.0	-9.0	56.0	33.0	-9.0	-9.0	102.0
5	6	1973	-9.0	-9.0	0.0	0.0	-9.0	5.0	45.0	133.0	36.0	0.0	-9.0	0.0	220.0
5	6	1974	0.0	0.0	0.0	0.0	-9.0	17.0	75.0	186.0	49.0	2.0	0.0	0.0	330.0
5	6	1975	0.0	0.0	0.0	0.0	1.0	29.0	200.0	94.0	74.0	7.0	0.0	0.0	409.0
5	6	1976	3.0	-9.0	0.0	4.0	23.0	38.0	63.0	157.0	41.0	5.0	2.0	1.0	337.0
5	6	1977	0.0	10.0	0.0	0.0	0.0	7.0	0.0	-9.0	-9.0	-9.0	-9.0	-9.0	17.0

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PRECIPITATION STATISTICS

COUNTRY	STATION	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL PRECIP
M	1	1972	0.0	0.0	31.0	0.0	0.0	0.0	0.0	25.0	42.0	1.0	0.0	0.0	99.0
M	1	1973	0.0	0.0	0.0	0.0	0.0	0.0	1.0	10.0	11.0	0.0	1.0	0.0	23.0
M	1	1974	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	11.0
M	1	1975	0.0	0.0	0.0	0.0	0.0	0.0	70.0	34.0	40.0	0.0	0.0	4.0	148.0
M	1	1976	0.0	0.0	9.0	9.0	0.0	0.0	1.0	22.0	10.0	0.0	0.0	10.0	61.0
M	1	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0
M	2	1972	0.0	0.0	0.0	0.0	0.0	19.0	1.0	0.0	25.0	0.0	0.0	0.0	45.0
M	2	1973	0.0	0.0	0.0	0.0	0.0	2.0	14.0	90.0	0.0	0.0	0.0	0.0	106.0
M	2	1974	0.0	0.0	0.0	0.0	0.0	0.0	17.0	88.0	13.0	4.0	0.0	0.0	127.0
M	2	1975	0.0	0.0	0.0	0.0	0.0	0.0	117.0	106.0	91.0	12.0	0.0	1.0	329.0
M	2	1976	0.0	0.0	1.0	0.0	0.0	2.0	31.0	60.0	135.0	0.0	0.0	13.0	242.0
M	2	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.0	0.0	0.0	0.0	0.0	37.0
M	3	1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	282.0	0.0	0.0	0.0	292.0
M	3	1973	0.0	0.0	0.0	0.0	0.0	0.0	1.0	32.0	9.0	0.0	0.0	0.0	42.0
M	3	1974	0.0	0.0	0.0	0.0	0.0	0.0	16.0	176.0	32.0	0.0	0.0	2.0	226.0
M	3	1975	0.0	0.0	0.0	0.0	0.0	0.0	71.0	43.0	367.0	5.0	0.0	3.0	489.0
M	3	1976	0.0	0.0	1.0	0.0	0.0	0.0	0.0	31.0	60.0	0.0	0.0	20.0	112.0
M	3	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0	0.0	0.0	0.0	0.0	17.0
M	4	1972	0.0	0.0	0.0	0.0	0.0	19.0	2.0	42.0	40.0	9.0	0.0	0.0	115.0
M	4	1973	0.0	0.0	0.0	0.0	0.0	4.0	12.0	83.0	19.0	0.0	0.0	0.0	118.0
M	4	1974	0.0	0.0	0.0	0.0	0.0	3.0	115.0	82.0	65.0	6.0	0.0	0.0	271.0
M	4	1975	0.0	0.0	0.0	0.0	1.0	10.0	87.0	129.0	36.0	5.0	0.0	0.0	268.0
M	4	1976	0.0	0.0	0.0	0.0	9.0	0.0	0.0	112.0	0.0	27.0	0.0	0.0	148.0
M	4	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M	5	1972	0.0	0.0	0.0	18.0	0.0	10.0	24.0	20.0	0.0	10.0	0.0	0.0	82.0
M	5	1973	0.0	0.0	0.0	0.0	1.0	0.0	0.0	70.0	37.0	0.0	0.0	0.0	108.0
M	5	1974	0.0	0.0	0.0	0.0	0.0	5.0	0.0	81.0	43.0	0.0	0.0	0.0	129.0
M	5	1975	0.0	0.0	0.0	0.0	1.0	37.0	141.0	95.0	284.0	0.0	0.0	0.0	558.0
M	5	1976	0.0	0.0	0.0	5.0	3.0	7.0	6.0	65.0	19.0	5.0	0.0	0.0	110.0
M	5	1977	0.0	0.0	0.0	0.0	0.0	0.0	54.0	28.0	0.0	0.0	0.0	0.0	82.0

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