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WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL NOTE No. 186

LAND MANAGEMENT IN ARID AND SEMI-ARID AREAS

WMO - No. 662

Secretariat of the World Meteorological Organization - Geneva - Switzerland

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WMO

The World Meteorological Organization (WMO), of which 160 States and Territories are Members, is a specialized agency of the United Nations.

It was created:

- To facilitate world-wide co-operation in the establishment of networks of stations for making meteorological observations as well as hydrological and other physical observations related to meteorology, and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological information;
- To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services;
- To encourage research and training in meteorology and, as appropriate, in related fields, and to assist in co-ordinating the international aspects of such research and training.

The machinery of the Organization consists of the following bodies:

The *World Meteorological Congress*, the supreme body of the Organization, brings together the delegates of all Members once every four years to determine general policies for the fulfilment of the purposes of the Organization, to adopt Technical Regulations relating to international meteorological practice and to determine the WMO programme.

The *Executive Council* is composed of 36 directors of national Meteorological or Hydrometeorological Services. It meets at least once a year to conduct the activities of the Organization, to implement the decisions taken by its Members in Congress and to study and make recommendations on any matter affecting international meteorology and related activities of the Organization.

The six *regional associations* (Africa, Asia, South America, North and Central America, South-West Pacific and Europe), which are composed of Member Governments, co-ordinate meteorological and related activities within their respective Regions and examine from the regional point of view all questions referred to them.

The eight *technical commissions*, consisting of experts designated by Members, are responsible for studying any subject within the purpose of the Organization. Technical commissions have been established for basic systems, instruments and methods of observation, atmospheric sciences, aeronautical meteorology, agricultural meteorology, marine meteorology, hydrology, and climatology.

The *Secretariat*, located at 41 avenue Giuseppe-Motta, Geneva, Switzerland, is composed of a Secretary-General and such technical and clerical staff as may be required for the work of the Organization. It undertakes to serve as the administrative, documentation and information centre of the Organization, to make technical studies as directed, to support all the bodies of the Organization, to prepare, edit or arrange for the publication and distribution of the approved publications of the Organization, and to carry out duties allocated in the Convention and the regulations and such other work as Congress, the Executive Council and the President may decide. The Secretariat works in close collaboration with the United Nations and its specialized agencies.

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FOREWORD

At its eighth session (1979), the WMO Congress endorsed the action taken by the Executive Committee in approving a WMO Plan of Action in the meteorological and hydrological aspects of the combat against desertification (Res. 17 (EC-XXX)). The Commission for Agricultural Meteorology, at its seventh session (Sofia, 1979), considered the importance of meteorology in agriculture in arid and semi-arid and desert-prone areas and established a Working Group on Agrometeorological Aspects of Land Management in Arid and Semi-arid Areas with Special Reference to Desertification Problems. The Working Group was asked to assess the meteorological factors which affect aspects of land management in arid and semi-arid areas; study their impact on desertification processes and the means for controlling them; and specify the climatic data and other sources of information, including remote sensing, required to assess better land management in these areas. The working group was composed of Dr I. G. Gringof (USSR), chairman; Prof M. Garabatos (Argentina); Mr F. A. Powell (Australia); Mrs S. Ghardaddou (Tunisia); Dr D.W. Fryrear (USA); Dr T. Boyadgiev (FAO); Dr F. Fournier (Unesco); Mr M. M. Verstraete (UNEP); Mr Y. El-Kawasma (ACSAD).

The present report is not exhaustive and does not include experience from all parts of the world. It is intended to provide some basic information required by meteorologists, agriculturists, pasture and livestock managers, and others working in arid and semi-arid areas.

I should like to take this opportunity to express the gratitude and appreciation of the World Meteorological Organization to all members of the Working Group and especially to its Chairman, Dr I. G. Gringof.

G.O.P. Obasi
Secretary-General

SUMMARY

The report identifies the meteorological factors which influence land-use and management decisions in arid and semi-arid areas and their role in desertification processes and control. It makes proposals and recommendations for further study and for the monitoring of agrometeorological aspects of land management in arid and semi-arid areas.

Agricultural production depends on the specific soil and climatic conditions of particular areas. Therefore the science of agrometeorology has been very much concerned with the assessment of moisture conditions, while various relationships or indices between climatic and meteorological elements and agricultural production have been evolved over the years. The first section therefore deals with the assessment of these conditions in arid and semi-arid areas, especially in rangelands where inappropriate land use, over-cultivation and over-grazing can lead to land degradation and desertification. Some of these relationships have proved useful in forecasting the state and yield of rangeland pasture vegetation. The report then summarizes the data requirements for assessing the primary production of pasture vegetation.

The next section of the report discusses the agrometeorological conditions affecting livestock production. The most important factors such as temperature and radiant heat, rainfall, wind, humidity and their effects on the animals, especially cattle, sheep, swine and poultry, are discussed. Pests and diseases are also mentioned. It is shown that the effect of meteorological factors on insects can be either positive and beneficial, as in the case of bees for the production of honey, or unfavourable, as in the case of insect pests (e.g. tsetse fly, locusts, mosquitoes).

The following section deals with major anthropogenic and agrometeorological factors which contribute to the diminution of vegetation cover, both in rainfed and irrigated agriculture. A description of the influence of meteorological hazards on desertification processes follows. The first topic discussed is drought as one of the most important causes of desertification and an attempt is made to explain by some specific cases that drought and desertification can interact and thereby be accelerated. Drought and desertification processes in rangelands, rainfed and irrigated agriculture are discussed. In irrigated agriculture, it is emphasized that care should be taken to avoid salinization and waterlogging; other causes of desertification, namely fire, erosion, pests and poor rangeland management, and ways of assessing their effects and controlling them are mentioned.

The last section of the report is devoted to the application of remote-sensing techniques (satellites, aerial photography) for assessing and monitoring the state and productivity of vegetative cover, soil moisture, surface water supply and desertification, and some examples are given.

SUMMARY

Résumé

Le rapport identifie les facteurs météorologiques qui influencent les décisions en matière d'utilisation et d'aménagement des sols dans les régions arides et semi-arides, et le rôle de ces facteurs dans le processus de désertification et la lutte contre ce dernier. Il contient des propositions et des recommandations pour un examen plus approfondi et l'observation des aspects agrométéorologiques de l'aménagement des sols dans les régions arides et semi-arides.

La production agricole est tributaire des conditions pédologiques et climatiques propres à telle ou telle région. La météorologie agricole a donc fait une place importante à l'évaluation des conditions hygrométriques, et divers indices ou corrélations entre les éléments climatiques et météorologiques et la production agricole ont été élaborés au cours des années. La première section du rapport contient donc une évaluation de ces conditions dans les régions arides et semi-arides, en particulier dans les terres de parcours où une mauvaise utilisation des sols, le surpâturage et des cultures trop intensives peuvent provoquer la dégradation des sols et la désertification. Certaines de ces corrélations ont joué un rôle utile dans la prévision de l'état et du rendement de la végétation dans les terres de parcours. Le rapport contient ensuite une brève récapitulation des données nécessaires à l'évaluation de la production primaire de végétation pour le pâturage.

La deuxième section du rapport traite des conditions agrométéorologiques qui influencent la production animale. Il y est question des principaux facteurs tels que la température et la chaleur de rayonnement, les pluies, le vent, l'humidité, et de leurs effets sur les animaux, en particulier les bovins, les ovins, les porcins et la volaille. Les parasites et les maladies sont aussi mentionnés. Il y est constaté que les facteurs météorologiques peuvent avoir sur les insectes des incidences favorables - comme dans le cas des abeilles pour la production de miel - ou préjudiciables, comme dans le cas des parasites (mouches tsé-tsé, criquet, moustiques, par exemple).

La troisième section du rapport traite des principaux facteurs agrométéorologiques et imputables à l'homme qui contribuent à la réduction du couvert végétal, aussi bien dans les régions de cultures pluviales que dans celles qui pratiquent l'irrigation. L'influence des catastrophes d'origine météorologique sur le processus de désertification est ensuite analysée. La sécheresse, l'une des principales causes de la désertification, est le premier thème abordé et des exemples précis sont cités pour démontrer l'interaction et l'effet d'accélération réciproque de la sécheresse et de la désertification. La sécheresse et le processus de désertification dans les terres de parcours, les régions de cultures pluviales et de cultures irriguées sont analysés. S'agissant des cultures irriguées, l'accent est mis sur la nécessité d'éviter la salinisation et l'engorgement des sols; les autres causes de la désertification - incendies, érosion, parasites et mauvaise gestion des terres de parcours - ainsi que les moyens d'en évaluer et d'en combattre les effets sont aussi mentionnés.

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La dernière section du rapport porte sur l'application des techniques de télédétection (satellites, photographies aériennes) pour l'évaluation et la surveillance de l'état et de la productivité du couvert végétal, de l'humidité des sols, des eaux de surface disponibles et de la désertification. Quelques exemples sont mentionnés.

Резюме

В отчете определяются метеорологические факторы, влияющие на землепользование и административные решения в аридных и полуаридных зонах, а также роль этих факторов в процессе опустынивания и его контроле. Даются предложения и рекомендации по дальнейшему изучению и мониторингу агрометеорологических аспектов землепользования в аридных и полуаридных зонах.

Сельскохозяйственное производство зависит от конкретных почв и климатических условий определенных районов. Поэтому агрометеорологическая наука в значительной степени занята оценкой условий влажности, в то же время на протяжении ряда лет выявлены различные взаимоотношения или индексы связи между климатическими и метеорологическими элементами и сельскохозяйственным производством. Первый раздел отчета посвящен оценке этих условий в полуаридных зонах, в особенности на пастбищах, где неправильное землепользование, излишняя обработка и излишний выпас могут привести к деградации и опустыниванию земель. Подтверждена полезность некоторых из этих взаимосвязей при предсказании состояния и урожая растительной массы на пастбищных угодьях. Затем в отчете резюмируются потребности в данных для оценки первичной продуктивности растительности на пастбищах.

В следующем разделе отчета рассматриваются агрометеорологические условия, оказывающие влияние на животноводство. Обсуждаются вопросы, связанные с наиболее важными факторами, такими, как температура и инфракрасная радиация, осадки, ветер, влажность и их влияние на животных, в особености на крупный рогатый скот, овец, свиней и домашнюю птицу. Упоминаются также эпизотии и болезни. Показывается, что влияние метеорологических факторов на насекомых может быть также положительным и выигрышным, как для пчеловодства при производстве меда, или неблагоприятным, как в случае насекомых-вредителей (например, муха це-це, саранча, комары).

Следующий раздел посвящается главным антропогенным и агрометеорологическим факторам, которые вносят свой вклад в уменьшение растительного покрова как при богарном, так и при орошаемом земледелии. Следует описание влияния опасных метеорологических явлений на процессы опустынивания.

Первым вопросом, который излагается, является засуха как одна из наиболее важных причин опустынивания, а также делается попытка внести ясность в некоторые конкретные случаи, при которых засуха и опустынивание могут взаимодействовать и взаимно ускоряться. Излагаются вопросы, связанные с процессом засухи и опустынивания на пастбищных землях при богарном и орошаемом способах земледелия. При поливном земледелии особый упор делается на внимание, которое должно быть уделено тому, как избежать засоления и переувлажнения; упоминаются другие причины опустынивания, а именно: пожар, эрозия, вредители и плохое управление пастбищным хозяйством, а также пути оценки их влияния и контроля за ними.

Последний раздел отчета посвящен применению методов дистанционного зондирования (спутники, аэрофотосъемка) для оценки и мониторинга состояния продуктивности растительного покрова, почвенной влаги, водоснабжения на основе поверхностных вод и опустынивания, а также приводятся некоторые примеры.

Resumen

El informe identifica los factores meteorológicos que influencian el aprovechamiento de tierras y las decisiones de ordenación en zonas áridas y semiáridas y su función en los procesos y el control de la desertificación. Hace propuestas y recomendaciones para otros estudios y para la vigilancia de los aspectos agrometeorológicos de la ordenación de tierras en zonas áridas y semiáridas.

La producción agrícola depende de las condiciones específicas y climatológicas del suelo de determinadas zonas. Por consiguiente la ciencia de la agrometeorología ha acordado gran interés a la evaluación de las condiciones de humedad, mientras que las diversas relaciones o índices entre los elementos climáticos y meteorológicos y la producción agrícola han ido evolucionando en el transcurso de los años. La primera sección se ocupa por lo tanto de la evaluación de esas condiciones en zonas áridas y semiáridas, especialmente en terrenos de pastos donde el aprovechamiento inadecuado de la tierra, debido al exceso de cultivos y de pastos puede conducir a la degradación y desertificación de la tierra. Algunos de estos vínculos han sido útiles para la previsión del estado y el rendimiento de los pastos en los terrenos de pasto. El informe resume después los datos que se precisan para evaluar la producción básica de pastos.

En la siguiente sección del informe se analizan las condiciones agrometeorológicas que afectan la producción pecuaria. Se examinan los factores principales tales como la temperatura y el calor radiante, la lluvia, el viento, la humedad y sus efectos sobre los animales, especialmente el ganado vacuno, ovino, porcino y las aves de corral. Se mencionan también las plagas y las enfermedades. Se demuestra que el efecto de los factores meteorológicos sobre los insectos puede ser positivo y benéfico, como en el caso de las abejas para la producción de miel, y desfavorable, como en el caso de las plagas de insectos (por ejemplo la mosca tsetse, las langostas y los mosquitos).

SUMMARY

La siguiente sección se ocupa de los principales factores antropogénicos y agrometeorológicos que contribuyen a la disminución de la cubierta vegetal, tanto en la agricultura de secano como en la de regadío. Describe a continuación la influencia de los riesgos meteorológicos sobre los procesos de desertificación. El primer tópico que se examina es la sequía como una de las causas más importantes de la desertificación y se trata de clarificar en algunos casos específicos que la sequía y la desertificación pueden ser factores mutuos de interacción y de aceleración. Se examinan la sequía y los factores de desertificación en los terrenos de pasto, la agricultura de secano y la de regadío. Se subraya que en la agricultura de regadío deben tratar de evitarse la salinización y el encharcamiento. Se mencionan también otras causas de desertificación a saber el fuego, la erosión, las plagas, un aprovechamiento deficiente de las zonas de pastos y la manera de evaluar sus efectos y controlarlos.

La última sección del informe se consagra a la aplicación de las técnicas de teledetección (satélites, fotografías aéreas) para evaluar y controlar el estado y la productividad de la cubierta vegetal, la humedad del suelo, el suministro de agua de superficie y la desertificación y se citan en ella algunos ejemplos.

PART I

1. APPLICATION OF AGROMETEOROLOGICAL DATA TO LAND MANAGEMENT IN ARID AND SEMI-ARID REGIONS

Introduction*

Agricultural production is not infrequently called "a plant in the open air" as the greater share of its production is realised directly under natural conditions. (Yu. I. Chirkov, 1979.)

The management systems of agricultural production are developed by man in a differential way depending on the specific soil and climatic conditions of particular areas. "Soil and climate are the principal and most important factors in crop-farming, the primary and inevitable determinants of yields." (V. V. Dokuchaev.)

Rational placement of various branches of agriculture, of individual cultivated crops and animal breeds, as well as agrotechnical terms, and systems and types of agricultural equipment are to a large extent dependent upon climatic conditions of the area and specific weather in the region of agricultural activities. In this connection the author would like to quote the outstanding founder of climatology and agrometeorology in Russia, A. I. Voeykov, who wrote that "meteorological conditions are of utter significance for agriculture; man has to study climate to turn its good aspects to mankind's advantage, and whenever possible to eliminate its adverse impacts, but to this end a lot of continuous and strenuous work is necessary; thorough study is needed to achieve success." (A. I. Voeykov, 1957.)

L. P. Smith writes in his book "Methods in Agricultural Meteorology"**: "There is little doubt that in certain countries there is a highly efficient state of affairs in regard to the sensible use of land for agricultural purposes. It is true that there are changes from time to time, induced by economic circumstances, or by minor fluctuations of climate, or by technical developments, but in the main they are in a good state of proved relationship with soil and climate.

There is also little doubt that major changes or development plans for the long-term strategic use of land involve heavy outlays of capital far greater than the operational costs in any one season. It is therefore all the more important that such changes or plans should be based on a sound appraisal of the climatic advantages and climatic risks. The science of agroclimatology aims at the interpretation of the climate or the expected variety of weather over a decade or so in terms of the most suitable form of crop production or animal husbandry.

If all the agrometeorological relationships were known so that each facet of the weather was correctly linked to each effect it has on agricultural processes, then it would be theoretically possible, no matter how intricate and laborious, to interpret the climate or consensus of weather into terms of land use. Manifestly this is not so; therefore, a state of affairs arises whereby progress takes place at both levels. A summary of agricultural events is linked to the summary of weather, and the relationships so implied are subjected to checksby agrometeorological investigations. For example, comparison of the areas wherein a given crop is grown, and where the highest yields are obtained, with the climate of such areas can give useful information regarding the weather limitations of the crop and the optimum growing conditions. Conversely, reliable findings in one particular aspect of agrometeorology

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* by I. G. Gringof (USSR).

**L. P. Smith "Methods in Agricultural Meteorology", Elsevier Scientific Publishing Company. Amsterdam-Oxford-New York, 1975, p. 12-13.

can be used as a criterion when extrapolating crop-weather relationships and helping in the correct introduction of a crop into a new area."

In agricultural practice (crop farming and stock breeding), assessment of soil moisture conditions for crops and natural meadow and pasture vegetation is very often made by agronomists using total precipitation for a year or its growing season. Such an approach is known to result in serious errors when objective characteristics of soil moisture conditions are prepared. Thus for example, in the zone of foothill plains and lower highlands in Uzbekistan and the Kola Peninsula, long-term average precipitation is 300-350 mm. However, in Uzbekistan this amount is sufficient only for spring vegetation of crops and natural grasses that, if there is no further precipitation, stop growing and wither at the beginning of high summer temperatures. Further growing of crops is only possible under irrigation. As for the Kola Peninsula, the same amount of precipitation creates excessive moisture conditions for crops.

This paradox is explained by the difference in the temperature regime of the territories considered and hence in unequal potential evaporation. In Tashkent it is 1 200 mm/year and on the Kola Peninsula, 300 mm/year.

Therefore, for agrometeorological support of agricultural production the assessment of moisture conditions is made using the ratio of the precipitation amount to potential evaporation.

Let us consider some of these methods. As far back as 1928, Selyaninov suggested the assessment of moisture conditions of a territory using the hydrothermal coefficient (HTC) where

$$\mathrm{HTC} = \frac{\Sigma r}{0.1\Sigma t}$$

where Σr is the total precipitation for the growing season (mm), $0.1\Sigma t$ is the potential evaporation (mm) approximately equal to the sum of mean daily air temperatures divided by 10 for the period when they constantly exceed 10°C.

Moisture conditions in various climatic zones are assessed with the help of this coefficient, but, as a rule, moisture conditions of individual years differ from their long-term average values. Therefore a table of probabilistic characteristics of moisture conditions in various natural zones (after Chirkov, 1979), is presented (see Table 1).

Shashko (1967) proposed an index of moisture conditions (K):

$$K = \frac{r}{\Sigma d}$$

where r is the total annual precipitation (mm), Σd is the sum of vapour pressure deficits (hPa).

Ivanov (1948) calculates K using the ratio of the total annual precipitation (r in mm) to the total annual potential evaporation (F)

$$K = \frac{r}{F}$$

Table 1 - Probability of years with various moisture conditions in various natural zones

Natural zones	Long-term average HTC for the period with $t^o > 10^oC$	Probability of years with various moisture conditions (%)					
		Dry	Very arid	Arid	Slightly arid	Wet	With excessive moisture
Taiga (excessively humid)	> 1.6	0	0	5	10	25	60
Taiga and deciduous forest (humid)	1.6-1.3	0	5	10	25	30	30
Forest-steppe (insufficiently humid)	1.3-1.0	0	15	25	30	20	10
Typical steppe (arid)	1.0-0.7	10	25	35	20	5	5
Dry steppe (very arid)	0.7-0.4	35	45	15	5	0	0
Semi-desert	0.4-0.2	75	20	5	0	0	0
Desert	< 0.2	98	2	0	0	0	0

Alpatiev (1969) determines K as follows:

$$K = \frac{W_1 - W_2 + r}{0.65 \sum d}$$

where:

W_1 is available moisture supplies (mm)at the beginning of vegetation;

W_2 is moisture supplies when a particular crop ceases vegetation;

$\sum r$ is the amount of precipitation (mm) during the growing season;

$\sum d$ is the sum of mean daily deficits of air humidity (mm) during the growing season.

Budyko (1971) expressed IMC by the formula:

$$IMC = \frac{r}{0.18 \sum t^o}$$

where r is the annual precipitation (mm) and $0.18 \sum t^\circ$ is the potential evaporation equal to the sum of temperatures multiplied by 0.18 for the period with air temperatures $> 10^\circ C$.

The productivity of above-ground mass of plant communities (agricultural ecosystems) is determined by main climatic factors, namely, the amount of heat and moisture (Grigoriev, 1954; Grigoriev, Budyko, 1965; and others). Another example of assessing the effect of heat and moisture upon the distribution of biomass over climatic zones is the use of annual values of radiation balance (R in kcal/cm^2/year) and the radiation index of aridity $J = \frac{R}{Lr}$, where Lr is the amount of heat in kcal required for the evaporation of annual precipitation (r).

Using the above method, Grigoriev and Budyko (1956, 1965) concluded that:

(1) The productivity of plant communities attains a maximum at some optimal value of $\frac{R}{Lr}$ close to unity and the decreases at constant R and at the change of $\frac{R}{Lr}$ values in both directions from an optimal one;

(2) At optimal $\frac{R}{Lr}$ the productivity of ecosystems is the higher the larger absolute values of R and Lr.

From $\frac{R}{Lr}$ it follows that the value of the radiation index of aridity exceeding unity means excess of warmth and insufficient moisture conditions in the land.

The index value lower than unity means excessive moisture conditions. According to this method, R and Lr are calculated from average long-term data.

While comparing R and $\frac{R}{Lr}$ with the amount of the annual increment of biomass (average over territory and average for many years) in centners of dry matter per unit area (hectare) in individual natural zones, Drozdov (1969) obtained a table given below in an incomplete form (Table 2).

Table 2 - Indices of productivity and heat and moisture regime
(after Drozdov, 1969)

Plant community or zonal landscape	Location	Annual increment of biomass (centners/ha)	R (kcal/cm^2/year)	$\frac{R}{L_r}$ (kcal/cm^2/year)
Tundra	Koryak Land, peninsula Kamchatka, USSR	25	15.7	0.41
Taiga	Arkhangelsk region, USSR	79	28.0	0.73
Birch forest	Moscow region, USSR	111	33.0	0.76
Oak forest	Voronezh region, USSR	81	36.0	1.03
Beech forest	West Europe	130	40.0	0.70
Meadow steppe	Kursk region, USSR	104	36.0	0.95
Dry steppe	Askaniya-Nova, USSR	87	46.0	1.84
Desert steppe	Mongolian People's Republic	24	37.0	2.28
Anabasis-Artemisia	Plato Ustyurt, USSR	12	45.0	5.77
Poa-Artemisia	Syria	24	66.0	4.81
Dry savannah	India	73	73.0	2.38
Savannah	Ghana	150	67.0	0.93
Subtropical laurel forest	Japan	205	68.0	0.69
Tropical rain forest	Thailand	320	70.0	0.47

Figure 1 shows the relationship between the productivity of ecosystems and moisture conditions expressed by the radiation index of aridity ($\frac{R}{L_r}$ kcal/cm^2/year). As can be seen, the annual increment decreases with increase of the aridity index and the character of the relationship is different in various thermal belts.

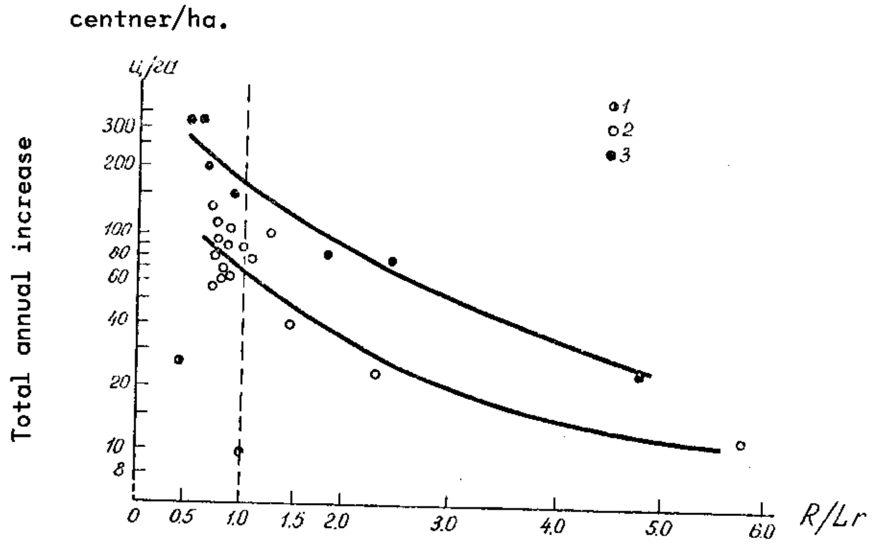

Figure 1 - Total annual increase (centner/hectare) in zonal plant communities as a function of moisture conditions in various thermal belts:

1 - Moderately warm belt
2 - Warm belt
3 - Very warm belt

(after Drozdov, 1969.)

Figure 2 presents the relationship between the productivity of ecosystems and radiation balance R (heat index). The annual increment of biomass increases with increase in R, the character of the curve being different in various sections of R values.

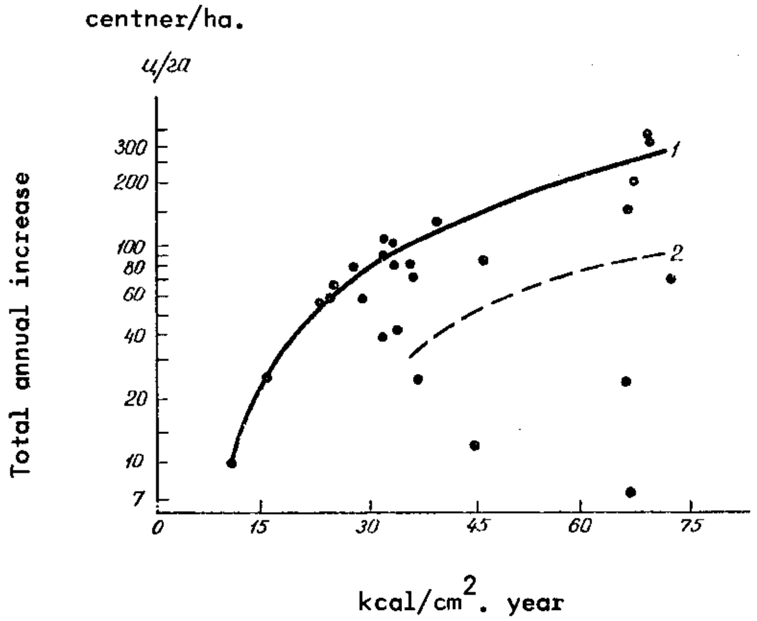

Figure 2 - Relationship between total annual increase (centner/hectare) in zonal plant communities and radiation balance (kcal/cm^2.year) at values of the aridity index: (1) from 0.4 to 1.4, (2) from 1.5 to 2.5. (after Drozdov, 1969)

More detailed climatic characteristics of natural pasture zones in West Siberian lowland, plains in Kazakhstan and deserts in Central Asia (USSR) are given in the book by Fedoseev (1964). Table 3 below summarizes them.

It is well known that a non-uniform seasonal distribution of precipitation is a characteristic of desert territories of the temperate zone. In this connection the application of annual values of meteorological parameters to desert areas may lead to errors in the establishment of relationships between the productivity of ecosystems and their moisture conditions.

The Desertification Map of the World prepared for the opening of the UN Conference on Desertification (UNEP, FAO, Unesco and WMO, 1977) in the scale of 1:25M gives the following characteristics of bioclimatic zones calculated from the formula:

$$\frac{r}{\sum EPT}$$

where r is the annual precipitation (mm) and ΣEPT is the sum of the actual evapotranspiration (in mm/year).

The map distinguishes the following bioclimatic desertification zones:

Very dry zone - < 0.03;
Dry zone - 0.03 - 0.20;
Semi-arid zone - 0.20 - 0.50;
Zone with insufficient moisture - 0.50 - 0.75.

Thus, various methods exist for estimating the effect of weather conditions (meteorological factors) on the heat and moisture conditions of vegetative cover (ecosystems) in various natural zones, and specifically in desert and semi-desert areas.

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Table 3 - Some climatic characteristics of natural zones (after Fedoseev, 1964)

Natural zones and subzones*	R (kcal/ cm^2/ year)	L_r (kcal/ cm^2 year)	$\frac{R}{L_r}$	Annual precipitation (mm)	Annual sum of positive air temperatures	Annual increment of vegetative matter (centner/ha)
Arctic semi-desert	<4	13	<0.3	220	<150	4
Arctic tundra	4	14	0.3	240	180	7
North tundra	8	16	0.5	270	540	12
South tundra	12	19	0.6	325	900	12
North taiga	15	29	0.5	490	1320	15
South taiga	20	25	0.8	420	2050	50
Broad-leaved forest	32	32	1.0	540	2800	56
Meadow steppe	23	20	1.2	325	2350	15
Typical cereal steppe	26	17	1.5	280	2730	10
Desert steppe	27	12	2.2	200	3300	5
Typical steppe	31	8	3.9	130	3740	4
Ephemeral semi-shrub desert	35	6	5.8	100	5500	7

*The names of natural zones and subzones and data on the annual increment of biomass are given according to Lavrenko, Andreev and Leontiev (1955).

A fairly complete list of drought definitions based on meteorological and hydrological parameters, soil moisture conditions and crop yields is given in "Assessment of drought" by Hounam, CAgM-V/Doc. 22 (1971) as well as in the report prepared by the CAgM Working Group on the Assessment of Drought and Agriculture, published as Technical Note No. 138 (WMO-No. 392), 1975.

A historical selective survey of drought indices is given by Landsberg in his paper "Drought, a recurrent element of climate", published in Special Environmental Report No. 5, "Drought-Lectures presented at the twenty-fifth session of the WMO Executive Committee". WMO-No. 403, 1975. Since it covers the principal meteorological parameters describing various degrees of aridity, we are reproducing it here with a reference to its author.

HISTORICAL SELECTIVE SURVEY OF DROUGHT INDICES (after Landsberg, 1975)

R. Lang (1915): Rain factor index $\frac{P}{T}$ ($<$40 arid)

E. de Martonne (1926): Index of aridity $\frac{P}{T+10}$ ($<$ 5"desert")

C. W. Thornthwaite (1931): P/E index $P/E = \sum_{I}^{XII} 1.65 \left(\frac{P_i}{t_i+12.2}\right)^{9/10}$ $P/E \lesssim 31$ semi-arid $P/E \lesssim 16$ arid

J. A. Prescott (1949): Effective rainfall = $0.54\ E^{0.7}$

R. Capot-Rey (1951): Improved aridity index $\frac{1}{2}\left(\frac{P}{T+10} + \frac{12p_i}{t_i+10}\right)$

H. P. Bailey (1958): $PE = P/1.025^{T+x}$ ($<$ 4.6 semi-arid boundary)

P. Moral (1964): Monthly aridity boundary $p_i = \frac{t_i^2}{1.0} - t + 20$

W. C. Palmer (1965): Drought severity index $X_i = \sum_{\tau=1}^{i} \frac{P-\hat{P}}{(\overline{PE}+\overline{R})/(\overline{P}+L)} / (0.31\tau+2.69)$

A. Y. M. Yao (1969): Moisture stress index $MSI = E/PE$

$$ET = S_\Delta + P \qquad S_\Delta \propto S_o$$

Simple indices: Meteorological 250 mm isohyet border of aridity
400 mm isohyet border of semi-aridity

Agricultural $<$ 90% of average crop yield

Statistical measures: (Conrad, 1941) Absolute average variability $v_a = \frac{\sum_i^n \varepsilon_i}{n}$; $\varepsilon_i = p_i - \overline{p}$

Relative variability $v_r = \frac{100 v_a}{\overline{p}}$

Coefficient of variation $C_v = \frac{100\,\sigma}{\overline{p}}$

Symbols

P or $\overline{p}$	Mean annual precipitation (mm)
E	Actual annual evaporation or evapotranspiration (mm)
p_i	Individual monthly precipitation (mm)
$\hat{P}$	Climatically appropriate water balance for existing conditions
x	Empirical coefficient
R	Recharge (mm)
S_Δ	Soil moisture loss (mm)
T	Mean annual temperature °C

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PE	Annual potential evapotranspiration (mm)
t_i	Individual monthly temperature (°C)
τ	Number of months
L	Loss (mm)
S_o	Antecedent soil moisture (mm)
σ	Standard deviation

1.1 Grazing lands*

The seasonal development, growth and yield formation of pasture plants in arid and semi-arid areas are determined by a whole set of ecological factors. The most unstable factors, varying in both time and space, are temperature regime and rainfall amount as well as the rain's intensity.

Correct use of data on these main factors which determine plant growth in arid regions permits an assessment of the agrometeorological conditions for plant growth and forecasting of plant development, growth and yield formation. In order to do this, the following actions are necessary:

(1) Regular meteorological observations at the standard times adopted in the particular country for meteorological stations (6);

(2) Soil moisture observations (8);

(3) Observations of the natural vegetative cover (pasture) (2, 5), including:

- Phenology;
- Growth;
- Status;
- Dynamics of yield formation.

The botanical composition of desert and semi-desert pasture types includes representatives of several plant genera, species and types with different fodder values, development rates and biomass-accumulation dynamics. Before making agrometeorological observations, it is therefore first necessary to select the main pasture plants which have most fodder value. For example, in wormwood/grasslands, the most important fodder plants are wormwood itself (*Artemisia sp.sp.*), annual grasses (*Bromus sp.sp.* and *Eremopyrum sp.sp.*), leguminosae (of the species *Astragalus* and *Hedisarum*), etc. The plants forming the basis of the plant community are described in botany as edificators and in agrometeorology as indicators.

Frequently, the same plant has different local names in different parts of a country or region which complicates the processing, comparison and generalization of observational data. The elimination of errors in the selection and naming of pastureland indicators must be done by specialists in geo-botany or pasture management, or by agronomists.

Other requirements are regular and simultaneous observations throughout the station network and the careful preparation of tables in an established format.

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*by I. G. Gringof (USSR)

Soviet experience in this field convincingly shows the need to include agrometeorological observations of pasture vegetation in the work programmes of meteorological stations.

As far as possible, the plots for observing pasture indicators should be selected in the immediate vicinity of the weather station and in similar terrain. This avoids the influence of other conditions of relief, soil and microclimatic peculiarities.

1.2 Rangelands (primary production): Identification and role of meteorological, climatological, hydrological and agrometeorological factors in the assessment of pasture growth

The main climatic cause of deserts and semi-deserts in naturally arid and semi-arid areas is the moisture deficit, since the amount of precipitation can be exceeded by potential evaporation seven to 30 times.

The mean annual rainfall amount is usually 60-175 mm but it is unevenly spread over the seasons and fluctuates sharply from year to year. In some parts of the world, it is even less (e.g. 9 mm in the Takla-Makan and less than 100 mm in all tropical deserts, whilst in a number of regions in North and South-west Africa and in western parts of South America there may be no rainfall at all for several years).

Desert and semi-desert areas in the temperate, subtropical and tropical latitudes (except mountainous regions) are characterized by high temperatures in the summer and large diurnal and seasonal fluctuations in both air and surface temperatures.

In deserts in the temperate belt, maximum air temperatures reach +50°C and in the tropical belt +58°C.

The soil surface in summer is heated up to +80° or +90°C, the daily air temperature range is 20°-30°C and the annual range 90°C. The high summer temperatures combined with the rainfall deficit, dryness of the upper soil horizons and frequent winds produce a low relative air humidity (14-20%).

Let us consider this in greater detail taking as an example the arid and semi-arid areas in the Soviet Republics of Central Asia and Kazakhstan.

The annual rotation of the earth around the sun causing changes in the circulation of the atmosphere produces, as is well known, the seasons.

In temperate zones the division into four seasons (winter, spring, summer, autumn) is based upon astronomical signs associated with the sun's position over the earth's surface.

Peculiarities in the development of the atmospheric circulation in arid zones are seen, in particular, in irregular precipitation during the year and its severe shortage in the hot summer months.

Analysis of observation data on the development and growth of natural pasture vegetation in the desert zone of Central Asian republics together with meteorological data has revealed four pasture-climatic seasons: cold moist winter, warm moist spring, hot dry summer, and warm moist autumn. This was done using agroclimatic indices of thermal conditions and characteristics of moistening by precipitation (Balashova et al., 1961; Babushkin, 1964; Gringof, 1967). The climatic peculiarities of deserts determine the seasonal development of their pasture vegetation.

(a) Cold moist winter

In the desert zone of Central Asia and Kazakhstan, the winter begins when the mean daily air temperature becomes persistently lower than +5°C and finishes when it persistently exceeds this value.

In the north of the Central Asian deserts, winter begins in the first ten-day period of November, in the central regions it begins in the middle of November and in the south at the end of November or the first half of December. However, periods when mean daily air temperatures do not exceed +5°C for a long time vary annually from 1 to 1.5 months.

In the south of Central Asia the winter (with temperatures below +5°C) is not long (20-30 days) but further north it lasts 130-145 days.

In the most severe winters the period of "genuine winter" is clearly defined, since mean daily temperatures are persistently below 0°C and the vegetative cover passes into complete winter dormancy. "Genuine winters" are observed in Central Asian deserts every year, but they last 10-15 days in the south and up to 105-127 days in the north.

In the warmest years, the so-called "vegetational winters" are observed when the vegetation of plants is not interrupted for more than 10 days owing to the thermal conditions (Babushkin, 1953). In various parts of Central Asian plains the frequency of "vegetational winters" is different. The January +4°C isotherm limits the area in which most winters are "vegetational" (south-western part of Turkmenistan); the +2°C and 0°C isotherms limit the areas with 80% and 60% of "vegetational winters", respectively, and the -2°C isotherm limits the area with 37% of such winters.

The January -6°C isotherm limits the area with an absolute prevalence of "genuine winters" (Babushkin, 1964).

For example, in the region of the town of Kerky 85% of years have "vegetational winters", in the region of Tashkent 43% and that of Khiva only 15%.

Winter vegetation of pasture plants is only observed at sufficient moistening of upper soil horizons (over 4 mm in the 0-20 cm layer of sandy soil and equal to or over 10 mm in the same layer of clay soil) and at air and soil temperatures above +5°C. Because of instability of the temperature regime in winter months as well as its characteristic diurnal variations, the vegetation of plants occurs intermittently. (Burygin, 1957). Plants, whether annuals, perennials or some semi-shrub forms, are able not only to use scant day-time heat in winter months actively but also to display high frost resistance during sudden intrusions of cold air masses or at night temperature minimum.

In some warm winters, ephemers have time to go through all the stages of their development from emergence to flowering. However, very often the intrusion of cold air masses stops vegetation of plants in blossom which lose "winter" hardiness.

Winter vegetation of plants is naturally possible only if there is some moisture in soil. On the average, in winter about 20%, 25-50% and 30-40% of annual normal precipitation respectively falls in the north, central and south of Central Asian deserts.

The winter moistening significantly affects the moisture supply regime in the rooting layer because evaporation from soil surface is negligible at this time. However, part of precipitation is spent on surface runoff and evaporation and part is accumulated in the soil horizons. According to Fedoseev (1964), in Kazakhstan the coefficient of winter precipitation accumulation in the 1 m layer of brown, sandy clay and clay soils is equal to 0.77, 0.70 and 0.62, respectively. In the Betpak-Dala desert this coefficient averages 0.75 for brown sandy clay soils (Beloborodova, 1964).

Comparison of total precipitation during an autumn-winter period from 1 October to the date when mean daily air temperature exceeds $+5^{\circ}$C (the beginning of spring) with moisture supplies in the soil layer of 0-50 cm on the above date in Kyzylkum, has made it possible to establish correlations for various soil types (Table 4).

Table 4 - Available moisture supplies in the soil (y) at the beginning of spring (as a function of total autumn-winter precipitation (x))

Soil type	Regression equation	Regression coefficient	Error of equation (mm)
Sandy desert soil	$y = 0.531x - 3.07$	0.81 ± 0.03	9.8
Grey-brown desert soil	$y = 0.427x + 1.42$	0.78 ± 0.03	9.4

The use of these equations allows one to fill the gap in available data on moisture supplies on the date of the beginning of vegetation.

In the south of Central Asia winter ends (and spring begins) in February-early March and in the north in late March-early April (Plateau Ustyurt).

(b) Warm moist spring

Increase in mean daily air temperature ($> + 5^{\circ}$C), and in duration of daylight signifies the beginning of spring, i.e., the first stage of a warm growing season.

In the north of Central Asian deserts, last spring frosts occur in the middle of April, and in the south in the first half of March.

Babushkin (1964) established the dependence of average dates of last spring frosts in Central Asian valleys upon average dates when mean daily air temperature exceeds +5°C in spring.

$$y = 0.93x - 0.27, \quad r = 0.93 \pm 0.01$$

where x is the average date when mean daily air temperature exceeds +5°C expressed in the number of days from 1 February to this average date, y is the most probable average date of last spring frosts expressed in the number of days from 1 March to this date.

Soil moisture supplies accumulated by the beginning of spring continue to increase due to spring rainfalls until the rise in air temperature and the increase in dryness of the air lead to a sharp increase of evaporation from the soil surface and transpiration of vegetative cover, which ultimately results in the loss of soil moisture supplies.

In Central Asia the greatest amount of precipitation falls in spring (February, March, April). Spring rains are characterized by high intensity and long duration, which result in surface runoff and sometimes even in mud-flows washing away the soil cover and causing damage to vegetation.

The temperature regime of this period (mean monthly air temperatures of between +13° and +16°C) on the whole favours the development of plants in deserts.

It is established that active vegetation of plants expressed by their development, growth dynamics and vegetative matter formation takes place at available moisture supplies over 4 mm in the sandy soil layer of 0-20 cm and over 6 mm in the sandy soil layer of 0-50 cm at average air temperatures for a ten-day period equal to +16°C +17°C for ephemers and 20°-24°C for semi-shrubs and shrubs.

More comprehensive ecological analysis of moisture conditions for natural pasture vegetation in Central Asian deserts allowed Nechaeva, Fedoseev (1965) and Gringof, Reizvikh (1977) to establish the index of moisture conditions for pasture vegetation in the Karakum and Kyzylkum (USSR):

$$IMC = \frac{B_b + O_c}{0.5 \sum d}$$

where B_b = available moisture supplies (mm) in the soil layer of 0-50 cm in the spring ten-day period when mean daily air temperature persistently exceeds +5°C (the beginning of active vegetation of plants); O_c = total precipitation (mm) for the period of active vegetation of plants (from the date when mean daily air temperature exceeds +5°C to the date when mean daily air temperature exceeds +20°C); $0.5 \sum d$ = half the sum of mean daily air humidity deficits (mm) for the above period.

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Half a sum of air humidity deficits has quite a definite ecological sense. In years with best yields ephemer grass stands during the period from renewal of vegetation (+5°C) to after 50% flowering spend the moisture amount equal to $0.46\Sigma d$ (or approximate to $0.5 \Sigma d$). This value is regarded by these authors as relative requirements of ephemer grass stands for moisture.

It is found that at IMC = 1.0 ephemer grass stands are fully supplied with moisture, at $IMC \geqslant 0.60$ moisture conditions are favourable, at $IMC < 0.60$ plants are short of moisture, and at $IMC < 0.40$ conditions for grass growth are bad.

On this basis the scale of agroclimatic regionalization of moisture conditions in spring in the desert zone of Central Asia is developed as follows:

$IMC \leqslant 0.20 - 0.39$ - very dry zone,

$IMC = 0.40 - 0.59$ - dry zone,

$IMC = 0.60 - 0.79$ - moderately arid zone,

$IMC = 0.80 - 1.00$ - moderately humid zone,

$IMC > 1.00$ - humid zone.

Productivity of pasture vegetation is primarily formed in spring and its amount is determined by heat and moisture conditions at this time (Table 5).

Table 5 - Moisture conditions in the Kyzylkum desert using IMC (in % of years)

Territory	Moisture conditions according to IMC				
	Very dry 0.10-0.39	Dry 0.40-0.59	Moderately arid 0.60-0.79	Moderately humid 0.80-1.0	Humid >1.0
Northern	10	2	-	-	-
Central	32	3	1	-	-
Southern	23	15	7	5	2
Total % of years	65	20	8	5	2

In the deserts of Central Asia and Kazakhstan, a warm moist spring lasts, on the average, 50-60 days.

At the end of April and especially in May the amount of precipitation sharply decreases and air temperatures increase.

Because of high temperatures, severe dryness of air and intensive transpiration of vegetative cover, root layers of soil rapidly lose available moisture.

Spring passes into summer when mean daily air temperature **persistently** exceeds +20°C.

(c) Hot dry summer

In the period when mean daily air temperatures exceed +20°C, further rise of air temperatures becomes slow, there is virtually no rain, and the hot dry weather which is characteristic of summer in Central Asia sets in. In the south such weather occurs at the end of April and in the north in May. In this transitional period from spring to summer the parching of over 50% of annuals is observed on desert pastures.

It is found that the parching of over 50% of annual grasses takes place when supplies of available moisture in the 0-20 cm soil layer are below 4 mm, mean ten-day air temperatures are +20°C - +22°C and the mean ten-day air saturation deficit is ≥ 19 hPa.

The parching of ephemers occurs in the ten-day period when any two of the above three indices are observed. The test of the procedure of evaluating conditions for parching ephemers in the Kyzylkum shows its high reliability equal to 93%.

The parching of wormwood (Artemisia L.) is found to occur at more severe xerothermal conditions than that of ephemers, namely, mean ten-day air temperature ≥ 24°C, mean ten-day air humidity deficit at 1300 hours ≥33 mb, available moisture supplies in the 0.5 m soil layer ≤6 mm. In the Kyzylkum, in spring wormwood shoots stop growing at mean ten-day air temperature ≥26°C, mean ten-day air humidity deficit at 1300 hours ≥35 mb and available moisture in the 0.5 m soil layer ≤6 mm.

In most of the desert zone in Central Asia, the summer rainfall is about 1-10 mm, i.e. 5-10% of the annual normal. However, in the majority of years in the central areas of the desert the amount of summer precipitation does not exceed 1-2% of the annual normal and only in the north is it 10-20%.

At high mean daily air temperatures, especially daytime air temperatures attaining 45° to 49°C, and at high temperatures of upper soil layers (in the Karakum, soil surface daytime temperatures reach 75° to 80°C), rare rains falling mainly in the north of deserts cannot significantly improve moisture conditions. All this is aggravated by high potential evaporation during this season.

Under such conditions, plants with short roots stop growing completely and plants which have developed, in the process of phytogenesis, a number of adaptation mechanisms allowing them to survive during this hot and dry period pass into the state of relative summer dormancy.

Despite a deep interrelation between desert plants and arid conditions, a dry and hot summer period is critical for their survival. Drought and dry and hot winds therefore play a special role in the life of plants.

As is well known (Tsuberbiller, 1959; Babushkin, 1964), the group of hydrometeorological factors used to describe the dry-wind situation mentioned above includes relative humidity or air saturation deficit, wind velocity and availability of moisture supplies in the upper soil layers; plant transpiration also depends on these factors to some extent.

For Central Asian conditions, air saturation deficit at 1300 hours may permit an estimate of the degree of aridity:

Slight atmospheric drought	50-60 hPa,
Medium atmospheric drought	60-70 hPa,
Severe atmospheric drought	70-80 hPa,
Very **severe** atmospheric drought	over 80 hPa.

The highest frequency of days with hot and dry winds is observed in July. A relationship has been established between an average number of days with dry and hot winds in July and the most probable average number of days with such winds during the period of May to September.

(d) Warm moist autumn

The autumn begins when mean daily air temperatures are constantly below +20°C. This occurs, on the average, in the second half of September and in the extreme south at the beginning of October.

Decrease in mean daily air temperatures favourably affects wormwood and shrubs from the family of Chenopodiacea; many species of wormwood begin flowering, and pericarps of Haloxylon sp.sp., Salsola richteri Karel, Salsola arbuscula Pall and other plants actively grow.

As a rule, cyclonic activity is resumed in October, causing rainfalls. As a result, moisture supplies are accumulated in soil. In some years a dry rainless autumn can last until November.

Due to autumn rainfall, decreasing air temperatures (but not below +5°C) and rising air humidity, soil moisture increases and favourable conditions are created for the autumn renewal of grass vegetation. But a warm and wet autumn season is not observed every year. Very often there are years when small amounts of precipitation or heavy precipitation at low air and soil temperatures do not allow the renewal of plant vegetation in autumn.

Depending on the weather conditions of the particular year, autumn renewal of vegetation may start from the beginning of October to December. The later the beginning of the wet autumn period, the less the duration of plant vegetation in autumn because of the beginning of winter cold. The wet autumn period lasts from the first autumn rains creating available moisture supplies of no less than 4-5 mm in the 0-20 cm soil layer to the moment when air temperatures are persistently below +5°C.

The duration of autumn is not constant either. It varies from year to year just like the season's starting date. In central areas of the Karakum it lasts only several days while in outlying districts of Central Asian deserts, in the zone

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of foothills of highlands, it attains 40-50 days, which is explained by the rainfall regime (Babushkin, 1964).

Fedoseev (1965) found that in the plains of Kazakhstan, autumn renewal of pasture plant vegetation begins in the ten-day period with air temperatures exceeding +5°C and available moisture supplies ⩾10 mm in the 0-20 cm layer of clay soils. The number of such moist warm ten-day periods determines the favourability of weather conditions for the renewal of pasture grass vegetation in autumn. For sandy and sandy-clay soils, the ten-day period is considered moist when available moisture supplies exceed 4-5 mm in the 0-20 cm soil layer and are ⩾ 8-10 mm in the 0.5 m soil layer (Balashova et al., 1961).

In most of the Karakum and Kyzylkum, a wet autumn is observed in 30-45% of years while in the south and north peripheries of the deserts the frequency attains 70-90% and 10-15%, respectively.

The autumn ends when mean daily air temperatures are persistently below +5°C (November).

The autumn's duration varies from 50 to 55 days in the north and from 70 to 75 days in the south.

1.2.1 Interrelations between agrometeorological conditions and pasture production

During the growing season, plants pass through a whole complex cycle of development from seed to seed.

As a result of a long evolution of arid zone plants under conditions of a hot and dry summer and a cold winter, a great variety of life forms developed which are fully adapted to such conditions; to survival under severe conditions of the struggle for existence and, primarily, for moisture.

In the Karakum, Nechaeva, Vasilevskaya and Antonova (1973) identified eight main life forms of plants whose development cycles are determined by an annual course of meteorological conditions, their particular location and peculiarities of the morphological structure of the plants themselves.

Variability of meteorological conditions from year to year affects the cycle of plant vegetation, the amount of annual increment of above-ground mass, fruit-bearing intensity, etc.

Due to the above peculiarities of rainfall distribution and temperature regime, desert pastures of the Central Asian republics and Kazakhstan are used for grazing depending on the pasture type (botanical composition), edibility and nutritive value of pasture plants, water availability and other economic and organizational factors.

During the growing season, plants pass through seasonal stages of development. The description of their morphological peculiarities, their vegetative cycles in Central Asian deserts is given in specialized scientific and methodical literature (Nechaeva, Nikolaeva, 1956; Gringof, 1962, 1966; "Instruktsiya" 1978, and others).

The dates of the vegetation commencement are found to determine, to a great extent, the yield of grasses. Thus for instance, in the south of Turkmenistan (the location of Badkhyz) high yields (5.0-6.0 centners/hectare) are formed in years when the vegetation begins in autumn (or winter) of the previous year. When it begins in spring, yields hardly attain 3.5 centners/hectare (Nechaeva, Prikhot'ko, Shuravin, 1971).

Owing to the parching of over 50% of grasses in late spring or early summer, grazing fodder becomes more coarse, dry and less nutritive.

As indicated above, in central and northern areas of Kyzylkum the renewal of vegetation in autumn occurs only in 10-15% of years; therefore the duration of green grass stands is associated only with warm and wet spring season and it lasts, on the average, 62-68 days in the north of the Kyzylkum, 71-74 days in its central areas and 74-83 days in the south and south-west. The duration of green grass stands varies from year to year over wide limits depending on heat and moisture conditions in spring. For example, it varies from 43 to 92 days and from 37 to 121 days in the north and the south of the desert, respectively.

In the paper by Nechaeva and Fedoseev (1960) it is found that the periodicity of flowering (and fruit-bearing) of some ephemers depends on agrometeorological conditions (the thermal regime in winter and moisture conditions in spring).

The favourability of the winter-spring period for flowering and fruit-bearing of ephemers (monocarpic plants) is shown in Table 6 according to criteria developed by the above-mentioned authors for the south of Turkmenistan.

Table 6

Seasonal favourability for flowering and fruit bearing of ephemers

Winter Number of days with minimum air temperature ≤-10°C	Spring Total precipitation for the period of March-April (mm)	Level of flowering and fruit-bearing for ephemers
≥15	≥100	Mass (>50%)
10-15	60-100	Medium (≃50%)
<10	< 60	Single plants or none

In years with different moisture conditions the height of grass plants as well as the length of young shoots (annual increment) of shrubs and semi-shrubs differ greatly. For example, the interannual difference in height is from 3-5 cm to 39 cm for Bromus sp.sp., from 8-10 cm to 45-50 cm for Poa bulbosa L., from 5-7 cm to 35 cm for Carex physodes M.B., the difference in the length of young shoots is from 6-7 cm to 35-45 cm for Artemisia terra-alba H. Krasch, from 3-40 cm for Calligonum sp.sp. and from 3-5 cm to 28-30 cm for Haloxylon persicum.

The above-ground mass produced by a plant community is determined by the morphological peculiarities of the plants as well as by the ecological conditions of their location. Thus, for instance, under identical climatic conditions the productivity of all the above-ground mass of Haloxylon persicum on sands constitutes 20.9 centners/hectare and of Salsola gemmascens Pall. on takyr soils 32.5 centners/hectare (Nechaeva, 1970).

The seasonal dynamics of pasture plant yields is associated with their biological development cycle (Динамика , 1957). For example, shrubs: Calligonum sp.sp. - maximum of the annual increment (100%) falls in the period of mid-April to mid-June, then gradual decrease down to 20-30% in September; Haloxylon persicum, Haloxylon aphyllum, Salsola richteri Karel. - maximum in June-August, then decrease down to 70% of the annual increment in December; semi-shrubs: Astragalus sp.sp. - maximum in April-May, decrease down to 60% in July and to 10% in November; Artemisia L. - maximum in May-June (100%), decrease down to 75% in July-early September, then rise up to 100% from mid-September to mid-November due to flowering and fruit-bearing, after its gradual decrease during the winter period.

According to observations by Nechaeva and others (1973), the above-ground mass of annual Salsola sp.sp. varies from 2% to 152% of the yield (100%) in a year with average weather conditions.

The yield of ephemer grasses may vary from 38 to 234% depending on weather conditions.

According to long-term data on fodder supplies on the Kyzylkum pastures determined over large areas by aerial photometric methods, the yield of pasture plants changes from year to year and from area to area (Table 7).

Table 7

Average yield of pasture plants, by area and year

Areas of Kyzylkum desert	Years when the yield was determined (centner/ha)											Average yield (centner/ha)
	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	
Northern	1.6	2.6	2.0	1.8	2.0	1.5	1.1	1.6	2.5	2.3	1.5	1.9
Central	1.5	1.7	1.2	0.9	2.5	0.6	0.6	1.0	1.5	1.1	0.7	1.2
South-eastern	5.2	3.2	3.5	3.5	3.0	4.6	3.1	2.8	-	3.5	-	3.6

As mentioned above, the variability of pasture vegetation yields depends on past agrometeorological conditions. As an example, we present Table 8 which shows yield as a function of many meteorological and agrometeorological parameters.

A number of years with calculated and actual yields were analysed to obtain the frequency of years with good, medium and poor yields (Table 9).

Such are main characteristics of the seasonal and annual variations of natural pasture vegetation resulting from agrometeorological conditions in the arid zone of Central Asian republics.

Table 8 - Empirical relations between above-ground yields and meteorological and agro-meteorological conditions in various types of pastures

Geographical region	Type of pasture	Equation	r, R	W_u (centner/ha)	Reliability (%)	Author, year of publication
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Central Karakum	Haloxylon, Carex physodes and other plants	$u = 0.01m + 0.002y + 2.8$	0.63 ± 0.13	± 0.5	89	Volosyuk, 1967
		$u = 0.02n + 0.005m + 0.0001y - 0.1$	0.90 ± 0.05	± 0.3	83	Volosyuk, 1967
		$u = 0.016m - 0.002n + 0.002y + 0.2$	0.91 ± 0.5	± 0.2	100	Volosyuk, 1967
		$u = 0.018m + 0.0036y - 0.67$	0.83 ± 0.038	± 0.57	-	Nurberdiev, 1978
South-eastern Karakum	Ephemers and Artemisia L.	$u = 0.016m + 0.002y - 0.153z + 0.17$	0.87	-	-	Fedoseev, Nechaeva, 1962
		$u = 15.0L - 1.7$	0.86	± 0.6	-	Artykov, 1968
		$u = 0.02m + 0.01y + 1.003$	0.75 ± 0.09	± 1.8	70	Volosyuk, 1967
		$u = 0.03n + 0.04m + 0.0002y + 1.28$	0.78 ± 0.1	± 1.8	75	Volosyuk, 1967
Areas south of Balkhash	Artemisia L. and Ephemers	$u = 0.032x + 0.0004y + 1.287$	0.88 ± 0.05	± 0.97	-	Fedoseev, 1964
		$u = 0.046x + 0.237$	0.82 ± 0.07	± 1.16	-	Fedoseev, 1964
		$u = 0.74m + 9.7$	0.87 ± 0.05	-	87	Korobova, Bedarev, 1970
Areas north of the Aral Sea	Different shrubs and Artemisia L.	$u = 0.67m + 23.1$	0.75 ± 0.07	-	80	Korobova, Bedarev, 1970
Central Kazakhstan	Artemisia L. and Ephemers	$u = 0.62Q + 18.48$	-0.91 ± 0.03	± 0.81	80	Korobova, Bedarev, 1970
Kalmyk Autonomous SSR	Artemisia L. and Ephemers	$u = 0.12m - 4.84$	0.77 ± 0.66	± 0.4	-	Belousova, 1974
	Kochia prostrata and Artemisia L.	$u = 0.19x + 0.25$	0.96 ± 0.02	± 0.6	-	Belousova, 1974

Table 8 (continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Kyzylkum	*Haloxylon*, *Carex physodes*, *Artemisia L.*, various Ephemers	$u = 0.017m + 0.0035y$	0.82 ± 0.02	± 0.5	80	Gringof, Reizvikh, 1972

Legend: u = yield of pasture plants, centner/hectare;
m = total precipitation;
n = the depth to which soil is wetted;
L = moisture coefficient;
x = available moisture supplies in the rooting layer;
y = sum of positive temperatures;
z = air saturation deficit;
Q = the number of sunshine hours in October of the previous year.

Table 9 - Frequency of years with various yields (in %) in the Kyzylkum during the period 1952-1975

Areas of Kyzylkum desert	Years with poor yields (<1.5 centner/ha)	Years with medium yields (1.5-2.1 centner/ha)	Years with good yields (>2.1 centner/ha)
Northern	18 - 44	50 - 52	6 - 30
Central	28 - 54	32 - 36	14 - 36
Southern	17 - 50	18 - 33	30 - 82
South-western	-	up to 5	95 - 100

1.2.2 Forecasting primary production of rangelands

The biological productivity of most species of pasture plants in arid and semi-arid areas is very closely connected with the moisture supply. The relationships between grass and pasture plants are characterized by coefficients of correlation with rainfall amount during the different periods of time which are most crucial for plant activity, $r = 0.75-0.90$, and by those with soil moisture reserves and soil moisture depth index, $r = 0.8-0.95$. Forms of shrubs with a fairly deep root system have a fairly stable annual biomass increase which is less strongly correlated to rainfall amount ($r = 0.7$).

In hot deserts and semi-deserts the relationships between yield and the amount of heat during the vegetation period are less close ($r = 0.33-0.42$). However, the air and soil temperature regime, especially during the period with most moisture supply, has much influence on plant development and organic mass accumulation.

Ideally, in order to forecast the primary production of rangelands, a reliable long-range forecast is needed for precipitation, temperature regime, air and soil moisture, solar radiation, etc. However, despite progress in long-range weather forecasting, the world's meteorological science still has no reliable forecasting method for practical application.

"Agrometeorological forecasting theory is based on general natural laws of the non-equivalence of environmental factors and of the irreplaceability of factors of life, laws of minimum and maximum and the law of interaction between factors of plant growth and development" (Fedoseev, 1981).

The main methods of agrometeorological forecasting are those of correlation analysis, although their possibilities are extremely limited.

Yield forecasting involves forecasting not only geophysical conditions of the environment but also corresponding biological effects of the multiple superpositions of, and interaction between, individual elements.

The technique for developing such forecasting methods for rangelands and compiling operational forecasts comprises the following:

- Consideration and assessment of the initial situation, i.e. the inertia factor in plant development and in the dynamics of individual meteorological factors causing the formation of moisture reserves in the soil;
- Consideration of climatic peculiarities in the region or district (rainfall rate, soil moisture regime, dates of the beginning of air and soil drought, etc.);
- Consideration of biological peculiarities of the main pasture plants (species of plants, their development cycles, the plants' competitiveness in their struggle for moisture in the plant community, etc.);
- Consideration of the conditions in the plants' habitat (flooding regime in estuary pasture vegetation; local relief, including slope exposures; soil moisture and temperature regime in different elements of the relief, etc.).

Empirical equations linking rangeland yield (primary productivity) with weather factors use a number of meteorological and agrometeorological indices (see Table 8).

Rangeland yield forecasting in arid and semi-arid areas of the USSR over the last 10-15 years has been fairly successful (80-90% accuracy). The forecasts have a period of validity of about 1.5-2 months.

Below are a few forecast equations to serve as examples (Nurberdiev, 1978; Fedoseev, 1964 and 1981):

(1) For rangelands in the northern half of central Karakum

$$y = 0.01x - 0.07, \quad r = 0.743, \quad Sy = \pm 0.04 \text{ t/ha}$$

(2) For rangelands in the eastern Karakum

$$y = 0.014x + 0.95, \quad r = 0.682, \quad Sy = \pm 0.05 \text{ t/ha}$$

(3) For rangelands in the foothills of Turkmenistan

$$y = -0.04x + 22.7, \quad r = -0.724, \quad Sy = \pm 0.13 \text{ t/ha}$$

(4) For rangelands in central Kazakhstan

$$y = -0.062z + 18.48, \quad r = -0.91, \quad Sy = \pm 0.081 \text{ t/ha}$$

(5) For various types of rangelands in Karakum

$$y = 0.893x + 2.238, \quad r = 0.808, \quad Sy = \pm 17.7\%$$

Here:
y = Pasture yield (t/ha)
x = Total cloud amount in October (oktas) in the preceding year
z = Number of hours of sunshine
r = Coefficients of correlation
Sy = Error of the equation (t/ha or per cent.)

With these equations the forecasts' validity is 5-6 months. In spring, the forecast can be improved using data on soil moistening depth (SMD):

$$y = 0.328x + 0.822\ \text{SMD} - 4.636, \quad R = 0.929, \quad S_y = \pm 11.2\%$$

where R is the coefficient of multiple correlation.

Yield forecasting on flood-plain rangelands in arid and semi-arid areas must take into account the hydrological regime of the flood-plain and river, the groundwater level and rainfall amounts in the non-flooded vegetation period for grassy-reed communities (Bedarev, 1979).

For different types of grass rangelands in the central flood-plain (Kazakhstan) the forecasting equation has the following form:

$$y = -0.044x^2 + 2.40x + 5.1/\eta = 0.88, \quad S_y = \pm 0.36 \ \text{t/ha}$$

where y = Yield (t/ha)
x = Duration of flooding in days
η = Correlation relationship
S_y = Equations' error (t/ha).

The yield-forecasting methods (primary production) developed in the USSR for rangelands are widely used for operational agrometeorological services in desert stockbreeding. As a result, the agricultural authorities in the Central Asian republics and Kazakhstan now have continuously updated agrometeorological information on the state and yield of rangeland vegetation.

1.2.3 Data requirements relating to primary production

As can be seen from Table 8, the following initial information is needed for assessing the state and yield of pasture vegetation:

- Climatic: including micro-climatic data and their vertical gradients (multi-year means of air temperature, rainfall amount over given time intervals, and various compound indices);

- Meteorological: air and soil temperature, air humidity, solar radiation, sunshine duration, evaporation, etc., over given calendar intervals or inter-phase periods of crop and pasture development;

- Hydrological: groundwater depth, degree of the groundwater's mineralization, dates, duration and depth of flooding on floodplains and river valleys;

- Agrometeorological: moisture and physical properties of soil, water reserves in the soil (rooting zone), soil surface and sub-surface temperatures and various compound indices;

- Biological: botanical composition of the plant community, plant development phases, growth dynamics, yield formation dynamics, plant stand density per unit area or design coverage of the soil by plants (in per cent), biometric parameters (bush dimensions, volume, fruit-bearing rate, proportion of bushes with different dimensions, proportion of plant parts which are edible and non-edible to animals, etc.).

These, and many other types of observations, are carried out in Hydrometeorological Services and their agricultural divisions. Naturally, the observations' volume, times and programme are determined by the physico-geographical characteristics of the region, the crops grown (or species of natural pasture plants) and the capabilities of each individual country.

However, the following general requirements exist for collecting various types of information on the state of plants and the ecological conditions of their habitats:

(1) An ecologically sensible selection of sites for the observations (the relief, soil and crops should, as far as possible, be the most typical for the whole field and rangeland, etc.);

(2) Correct selection of plant indicators which well reflect the composition and state of plants in the community;

(3) Regular observations;

(4) Synchronous observations of the growth of crop components and a set of meteorological (hydrological) observations;

(5) Careful recording of the observations in standard formats permitting statistical processing of the data according to the given samples.

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2. LIVESTOCK (secondary production)*

Land management in arid and semi-arid areas can benefit greatly from the application of agrometeorological methods. A data bank can be used to generate and test models which are geared to assist management, productivity, etc. Economic aspects of livestock production can be evaluated and decisions taken on whether the improvement in productivity due to climate modification is economically beneficial.

A knowledge of the response patterns of livestock to weather enables the manager to take suitable managerial action and to plan future programmes. Real time weather forecasts and warnings can be geared to the economic increase in productivity; warnings of heat waves, cold spells, strong wind and driving rain, weather conducive to the outbreak of disease and pests can initiate action to avert loss of productivity.

Models can be employed to gauge the effect that seasonal variation of weather has on quantity and quality of livestock. The storing qualities of livestock products, transport to market, etc. are all influenced by the weather experienced during the current season.

A data bank can be made to serve as a yardstick in the management of livestock. For a given locality it is possible to use the data bank to derive various managerial aids, e.g. to predetermine:

- The type and quality of shelters required for optimum production;
- The type of livestock best suited to the local climate;
- Probability charts for outbreaks of disease and pest infections;
- Cost benefit considerations for various management roles;
- Population and location of feral animals.

2.1 Meteorological factors affecting livestock and their productivity including water availability conditions

Water is the major constituent of most plants and animals; it is also consequently an essential ingredient of diet. Lee and Coughlan (1978) have pointed out that in tropical parts of Australia approximately ninety per cent of the incident rainfall occurs during the wet season; hence livestock in such areas require stored water for survival throughout the dry season. As vegetation also requires water for growth, grazing cattle in these areas need to be able to migrate in order to achieve a subsistence diet throughout the year.

Besides natural rainfall, water is also available from underground sources. Man has utilized this source of water particularly in arid or marginal rainfall areas both for livestock and in some cases for vegetation. In dry periods specifically, the availability of water and vegetation attracts feral animals. In fact the establishment of a supply of bore water at strategic places around Australia has enabled the feral population to increase to a number far in excess of that which would have resulted without the supplementary water holes. Although the supply of bore water is necessary for domestic animals in arid areas, it has promoted severe competition for available edible vegetation and water.

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* by F. A. Powell (Australia)

During the period leading up to a drought, livestock are forced to overgraze and the denudation of the pasture allows wind erosion and subsequent desertification to occur. Droughts in Australia have been so severe that mass destruction and burial of livestock have been necessary to avert death of the livestock by starvation. Drought can be lethal for livestock and conducive to desertification.

With an excess of natural rainfall flooding often occurs. Such an occurrence can be lethal and also cause erosion and structural damage to the housing of livestock, etc.

Water for pasture production is ultimately received from natural rainfall. A data bank can be utilized to provide an arrangement of rainfall data in decile form. This tabulation can be used as a powerful management aid. Some benefits of this system which have a bearing on livestock are:

- Maintenance of a continuous drought watch;
- Preparation of bulletins showing serious or severe rainfall deficiency;
- Probability assessment for a given amount of rain at a locality for each month of the year;
- Adjustment of livestock numbers on a property according to decile-ranked rainfall as an anti-desertification measure;
- Water storage from natural rainfall can be assessed on a probability basis for management information.

It is necessary to regulate the number of cattle permitted to graze specific areas so that pasture and land degradation will not ensue. Again a large feral population makes such a scheme difficult. However, the practical use of rainfall deciles can be a helpful management tool. The use of rainfall deciles should give an indication of the relative potential of an area to produce grazing pasture as well as the likelihood of drought. The occurrence of a dry spell or drought as indicated by rainfall deciles in the first few categories could be at a time when food reserves are scarce and the temptation for farm managers to overgraze their pastures would be very great. Although livestock may be in competition in some cases for available pasture, the number of livestock that is permitted to graze a specific area should be directly proportional to the rainfall deciles both present and past. Special cases may also exist where decile-related measures may need to be taken to sponsor pasture establishment.

Satellite data should also be employed to help management assess the replenishment and depletion of water in an area. Satellite-derived charts of radiation can be used with fields of temperature, dewpoint and wind, based on satellite data to produce a field of Penman evaporation. The preparation of routine water balance maps would indicate surplus and deficiency areas of water.

Employment of these maps with a suitable model, e.g., Baier, Robertson (1966), could provide an estimate of soil moisture for various soil types. This information would help the manager determine the firmness of the surface and whether it would be damaged by cattle. Initial water loss for flood considerations could also be obtained from this data and would alert the manager to the possibility of flooding. Decisions on supplementary watering for growth of pastures can also be made on the basis of a soil moisture budget.

Disease of livestock is often aggravated by meteorological conditions. Pests can attack livestock or decimate the vegetation, necessary for the livelihood of livestock.

Meteorological models can be used to delineate probable areas of dispersion of pests and diseases. Both meteorological observations and forecasts can indicate whether an epidemic of pests or disease will eventuate. Probability maps of occurrence of disease or pests can be derived from a data bank using the appropriate meteorological indicators. The translocation of cattle pests such as the 'screw fly' can be forecast using meteorological parameters. A heavy overcast and a high humidity will promote the spread of a virus such as foot and mouth disease; such managerial advice is essential to veterinary officers faced with the task of control or eradication of this disease. Knowledge of seasonal rainfall and temperatures can be used to assess the likelihood of a forthcoming locust plague and preventive measures can be planned.

Thunderstorms associated with squalls, hail, tornadoes and lightning can all lead to the demise of livestock.

It is not unusual for a national weather service to provide warnings of thunderstorm activity. If radar surveillance is available then the severity and movement of individual storms can be monitored. The enhancement of regular satellite pictures may also be an aid in delineating severe local storms. Such advice can assist in protecting cattle.

Wind can affect livestock both directly and indirectly. Some ill effects are:

- Chilling associated with rain causing hypothermia during lambing and shearing of sheep;
- Translocation of pests or noxious weeds, e.g. locusts, screw fly, etc.;
- Spread of micro-organism diseases, e.g. virus bacteria, etc.;
- Wind erosion;
- Structural damage;
- Promotion and spread of bushfires.

Some of the beneficial aspects are:

- Ventilation;
- Cooling;
- Translocation of seeds necessary for food generation.

The Bureau of Meteorology in Australia issues warnings of cold winds and driving rain which, during lambing and shearing, can cause hypothermia in sheep. Whenever the forecast of a combination of rain and wind chill indicates that hypothermia is likely in newly shorn and newly born sheep a warning is issued to farmers to bring the susceptible animals into shelter as sheep do not necessarily seek shelter of their own accord.

Advice can be given for potential translocation of pests and disease particularly when a good interdisciplinary relationship exists between agriculturist and meteorologist.

Warnings of strong winds which may cause structural damage or enhance the spread of bush or forest fires can be supplied by a national meteorological service.

Examination of the data bank often helps soil conservationists to take action to avoid erosion.

Generally speaking, temperature regulates growth according to whether values are optimum or unfavourable. Temperature lapse also plays an important role. Both temperature and temperature lapse can play a major role in the production, release, uptake, dispersion and even deposition of bacteria, viruses or fungi spores, etc. which may affect livestock either directly or indirectly.

High temperatures are detrimental to productivity for most livestock. Low temperatures do not generally present the same problem. It is easier for livestock to generate heat to combat low temperatures by eating and moving about than it is for them to dissipate heat when air temperatures are high.

Solar radiation promotes the curing of hay for livestock. A high solar radiation load can promote hyperthermia and even sunburn on some pigs with a sensitive coat. If the radiation load is excessive as it is in parts of Northern Australia then it can prevent the establishment of vegetative growth to feed livestock. In these circumstances it is necessary to provide shelter to establish plants. When the radiation amount is too low, on the other hand, then vegetative growth is restricted. Low values of radiation, i.e. excessive cloudiness together with relatively high humidity, say above 60 per cent , can sponsor the spread of a disease such as foot and mouth disease. The operational use of satellite data can assist in the provision of managerial information in these instances.

Atmospheric humidity can affect the survival of bacteria and viruses. High humidity may also cause stress for livestock that lose heat by a combination of sweating and evaporative cooling. High humidity can also promote disease in vegetation on which livestock rely for survival.

2.2 Assessment of agrometeorological conditions for livestock productivity (meat, milk, etc.)

The supply of water at all times will be a limiting factor to livestock productivity. Water is of course essential for drinking purposes, however the availability of drinking places should be such as to provide for the essential needs of livestock but be sufficiently restrictive so as to discourage the proliferation of feral animals; the latter provide competition for available pasture and are potentially capable of hosting and spreading disease.

According to Tromp (1980):

(a) The thermal effect on the sensible heat exchange between an animal and its environment is not defined physiologically by the solar radiant energy absorbed but by the heat exchange. The heat exchange at the base of an animal's coat can be assessed in terms of the effect of insolation on total production and dissipation of heat by sweating, respiration and sensible exchanges. The exchange is affected by the thermal resistance of the coat, the convective heat transfer and the penetration depth and transmission of solar radiation onto the coat.

(b) Animals which are 'light-active' tend to show a shortening of the period between active phases if light intensity (with continuous exposure) increases; 'dark-active' animals tend to show a lengthening of the period with an increase in the light intensity (Aschoff, 1961).

(c) The limiting factors for livestock living at high altitudes appear to be the lack of available food and water, lack of sunshine and the thinness of the atmosphere which makes breathing extremely difficult. The grazing of livestock at altitudes between 2500m and 3700m during the warmer periods of the year results in many poorly acclimatized animals having difficulty in breeding or being afflicted by 'brisket disease' which can cause intense dyspnoea, leave the animal unable to tolerate even mild exertion and may lead to cardiac failure. Other animals when taken to high altitudes are susceptible to hypertension of the pulmonary artery. The incidence of 'brisket disease' in cattle herds native to sea level is between twenty and thirty per cent, whereas the figure is between one and two per cent for cattle native to high altitudes.

The thermoregulatory mechanisms are located in the hypothalomus in the brain and regulate the physiological processes which are involved in balancing both heat production and heat loss in animals; such mechanisms vary for different animals and according to Tromp (loc.cit.) have a major influence on the following:

- General health of animals;
- Cause of triggering of animal diseases;
- Variation in hair or wool growth;
- Reproduction and quality of animals;
- Resistance of animals to extreme climates;
- Variations in milla production.

Heat and cold both affect a number of an animal's physiological mechanisms. Animals lose heat by respiratory thermoregulation as well as evaporative thermoregulation (except for animals such as swine where no or few sweat glands are available). Tromp (loc.cit.) states that thermoreceptors in the skin or of the hypothalamus may increase the respiratory ventilation of the ox tenfold, the sheep twelvefold, the rabbit fifteenfold and the dog twenty-threefold.

The effects of meteorological elements on some specific animals will now be considered as detailed by Tromp (loc.cit.).

Sheep

In a hot climate, sheep are capable of rapidly reducing the temperature of their brain whilst the internal body temperature is being slowly reduced by panting; this ability to prevent cerebral overheating partly accounts for the high heat tolerance displayed by sheep. After a lowering of the brain temperature has been achieved sheep continue to reduce the deep body temperature by panting. In addition to this thermoregulatory mechamism sheep lose water continuously by evaporation due to respiration, passive diffusion and active expulsion through the skin. The control and importance of the contributions to total water loss and to heat loss in sheep are in many ways different from other genera because sheep carry a fleece of continuously changing length. The rate of water-vapour loss from an animal depends on the water-vapour pressure gradient from its surface to the adjacent air. The absolute humidity of the air together with the availability and temperature of any aqueous solution at the interface between the animal and the environment determines the water-vapour pressure gradient; the latter and the rate of sweat evaporation are reduced where salts accumulate on the skin as sweat evaporates and subsequent surface fluids may become saturated. Whenever sweat evaporates from the tips of the wool away from the body surface, the heat of evaporation is drawn from the air and no cooling of the body results.

In a thermoneutral environment, the rates of metabolism or evaporation do not increase. In such an environment, for unshorn sheep, their heat loss by evaporation is approximately 25 per cent; equal amounts of this heat loss are from the skin and the respiratory tract. Shorn sheep have thermoneutral temperatures of approximately 25° to 30°C and at this temperature the proportions of total heat loss attributable to respiratory, cutaneous evaporation and to non-evaporative processes are similar to those of unshorn animals at 10°C. Both heat production and heat loss in sheep increase below thermoneutral temperatures. In both shorn and unshorn sheep the increase in heat loss is almost entirely by non-evaporative processes, although exposure to very cold conditions does cause a small increase in pulmonary ventilation and presumably in respiratory evaporation. Evaporative heat losses predominate when temperatures exceed thermoneutrality. The increase in evaporation in unshorn sheep results largely from panting and only slightly from an increase in cutaneous loss of water.

Swine

The newly born pig is susceptible to cold weather; prolonged exposure of a newly born pig by itself to the cold can lead to its death by hypothermia, hence shelter is invariably provided. If the newly born pig is exposed to cold with other members of the litter then the behavioural property of huddling together enables the entire litter to withstand the cold more readily. Tromp (loc.cit.) explains that the poor thermoregulation of the newly born pig affects its glycogen and protein metabolism. Three- to eight-week-old piglets have difficulties in absorbing sufficient iron in a cold humid environment, so acquiring a pale skin colour. Consequently, shelters are provided for pig litters with an initial control temperature near 30°C and relative humidity 80 per cent, which is gradually lowered to 60 to 70 per cent with a temperature just below 20°C. The floors and walls of the shelter are insulated to prevent rapid cooling.

Because the mature pig cannot sweat effectively and because its rate of respiratory heat loss is limited, a sow or boar when exposed to hot dry conditions for a significant period can die of hyperthermia. Although the pig does not sweat it has the habit of wallowing in mud or water during hot weather and in the absence of water the pig may wallow in its own urine and faeces. The application of a paste of mud or faeces prolongs the time of water-loss by the order of one or two hours and ensures that the major heat source needed to vaporize the water comes from the pig's body. Water vaporized from the hair of the pig may use heat from the environment and consequently produce negligible cooling to the pig's body. The evaporative heat loss achieved as a result of wallowing avoids the problems of water and salt balance which

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can occur in panting and sweating animals. The ventilation rate per unit time in pigs with a high body temperature increases by a factor of about three which is similar to that for cattle but less than that for sheep. Under cold conditions with rain, the absence of a thick hair coat would prove to be disadvantageous. The cooling of the pigs' coat under these conditions would take heat from the body by evaporative cooling, whereas with the sheep, which is protected by its fleece, the evaporation can take place from the tips of the wool coat using heat from the environment. Shelter and spray cooling are invariably provided for domestic pigs as well as wallowing facilities. Wild boars, etc. are natural to swampy woodlands where shelter and wetting facilities exist.

Cattle and Ungulates

The physiological processes involved in balancing heat production and heat loss in animals are governed by thermoregulatory processes in the body which differ for different animals. If any of these processes malfunction in any way then the health of the animal could be seriously affected. Both heat and cold affect a great number of an animal's physiological mechanisms that control susceptibility to disease, production of wool, milk, hair and the reproduction and quality of cattle. As well as evaporative thermoregulation, respiratory thermoregulation plays an important part in cattle. Animals do not grow and produce as well in very hot climates as they do in temperate or cold climates. Heat stress together with high humidity adversely influence appetite and vitamin deficiencies may ensue. As pointed out by Tromp (loc.cit.) cows are better suited to low temperatures than high temperatures; the heat production in a non-gestating, non-lactating cow is of the order of 10^4 K cal day $^{-1}$. This heat production is doubled if the cow is yielding 20 kg of milk per day. Cows have poor sweating facilities as skin moisture evaporation reaches a maximum at only 17°C. The heat exchange between cattle and the environment is not determined by the solar energy absorbed as much as by the heat exchange at the base of its coat. The heat exchange is affected by the thermal resistance of the coat, the convective heat transfer and the penetration depth and transmission of solar radiation into the coat. Arid zone animals ideally should have a coat that is very pale in colour, relatively deep, be of a high bulk density and, possibly, glossy.

The general resistance of the offspring to climatic stress and parasitic diseases can be considerably improved by cross breeding. High environmental temperatures affect the fertility of various animals; in such cases it is possible that the reduced reproductive efficiency may be related to reduced food intake.

Feral animals such as the pig and the buffalo threaten the ecology of tropical parts of Australia. Besides consuming vast quantities of life-supporting vegetation, the 800 kg water buffalo does irreparable damage to the soil structure by pounding and churning the top soil. The habits of these animals to follow the same track daily, furrows out channels; the swim channels which are created alter the drainage system and the natural salt balance, amongst other things. Wild water buffalo pose a threat to the livestock of the country because they can be a reservoir for disease. One saving grace for the water buffalo in Australia is that it routs the wild pig population from its habitat. The water buffalo keeps itself cool by wallowing in mud or immersing itself in water for durations of the order of five hours daily.

Poultry

Weather and climate influence birds indirectly through food intake; a more direct influence occurs through temperature and solar radiation which affect the production of sexual hormones, the sexual ratio and the laying rhythm of fowls (Tromp, loc.cit.). Birds, like mammals, have relatively large surface areas from which heat is lost; they have a higher normal body temperature than mammals, usually higher than 40°C.

Shelters and cages are invariably provided for domestic poultry and hence this group shows a fairly high tolerance to cold under shelter conditions. The optimum environmental temperature for week-old chickens according to Tromp (loc.cit.) is around 35°C and at maturity ranges from about 18°C to 24°C.

High seasonal temperatures produce both depressed growth and a decreased survival rate. Excess body heat needs to be dissipated via sensible and latent heat. Conduction, convection and radiation account for dissipation of sensible heat whilst latent heat is lost by evaporation of water from the skin surface and through the respiratory tract. With poultry, practically all the latent heat is lost through the respiratory tract and hence ambient relative humidity is extremely important for poultry growth and survival at high temperatures.

Light has an important effect on the laying rhythm of hens. Many domestic fowl are sensitive to seasonal influences, e.g. there is a maximum production in spring in temperate zones of the northern and southern hemispheres whilst production is equal throughout the year in the tropics. The change of hours of daylight is a dominating factor in the seasonal effect on the laying rhythm. Tromp (loc.cit.) gives the explanation that light stimulates the pituitary and a follicle-stimulating hormone is secreted; hens ovaries are stimulated to activity and the egg follicles develop and mature. Between the secretion of the ovulation-inducing hormone and ovulation itself, a fairly constant period of about eight hours elapses.

Insects

Generally speaking, the function of insects in the environment can be both favourable (e.g. bees) and unfavourable, such as locust plagues. The estimated loss of crops and hence livestock fodder attributed to pests has been estimated at around 13 per cent. As well as having an indirect effect on livestock, insects can affect cattle directly and cause infestation, disease, general debility, etc.

Insects generally exhibit a higher sensitivity to factors in the physical environment than do the higher animals and this is shown particularly as a result of their highly developed degree of orientation giving rise to changes in their surroundings. Tromp (loc.cit.) has listed a number of properties peculiar to insects:

(a) Temperature is a dominant factor in the development, behaviour, reproduction and survival of insects;

(b) Humidity has an important influence on activity, distribution and survival. Insect transpiration affects water balance, restricts metabolism and retards development in some species. There is a high correlation between humidity and flight and the dispersion of insects. The duration of activity in a periodic flight is limited by low humidity;

(c) Light influences the behaviour of some insects. The abundance of some nocturnally active biting flies such as the tsetse and the mosquito is also related to lunar cycles within the 'fly season';

(d) Atmospheric pressure changes influence the activities of mosquitoes either as a direct mechanical effect or indirectly through alteration of meteorological variables such as wind which has a considerable influence on the activity and orientation of flying insects, especially in their dispersal from breeding grounds;

(e) Rainfall promotes the abundance of insects such as the tsetse fly and the mosquito;

(f) Electric fields have been reported to have varying effects on insects, e.g. :

Flying insects tend to be repulsed when they approach a positively charged screen;

Worker bees increase their number of foraging flights during periods of atmospheric electrical activity;

Guard bees become hostile when alternating potentials are placed on either side of the hive entrance;

The blow-fly shows greater flight speeds if treated with positive ions and more moderate speeds if treated with negative ions.

2.3 Forecasting of the quantity and quality of livestock products

Forecasting the quantity and quality of livestock products must also involve, to a certain extent, an assessment of likely crop and pasture conditions, water supply, incidence of diseases and pests, e.g. locust plagues, as well as consideration of factors such as acclimatisation.

Acclimatization is an important element in the rearing of livestock and the occurrence of unusual weather phenomena generally has an effect which results in loss of productivity.

The direct and indirect effects of weather determine the performance and even the survival of livestock. As a consequence the quantity and quality (e.g. storing qualities, tenderness of meat, etc.) of the produce can be affected which in turn has an effect on the economics of the particular venture.

2.3.1 Quality considerations

It has been found that cattle in the tropics, especially those under stress due to lack of care and management, are liable to be of poor quality, e.g. samples of beef produced under such conditions have been found to be tough. High temperature and humidity are the main meteorological factors which determine production and quality in the tropics. Extreme heat stress associated with high humidity tends to affect the appetite and growth of tropically based livestock. Provided that sufficient water and fresh nutritious forage are available in an environment where humidity is low and that there is sufficient air movement to evaporate animal sweat, then normally high values of air temperature alone need not suppress production. This is particularly so if the diurnal temperature range is high. Webster (1973) demonstrated that cattle can adapt to temperatures as low as -11°C to -22°C; cattle so adapted grow steadily throughout the year and the potential yield could be greater than for the tropics. Confinement of cattle tends to improve both quantity and quality but the closer contact makes the possibility of disease outbreak and stress problems more likely. According to Tramp (loc.cit.) meteorological stress has an affect on tenderness, flavour and juiciness of meat. The colour of the slaughtered animal fat when subjected to high humidity and slow chilling in still air results in the fat being more yellow. Beef production under hot conditions can be highly successful using a certain type of cattle (Bos indicus). The water buffalo (Bos bubulos) produces tasty meat that can be produced under still more stressful tropical conditions. It has been stated that the world's greatest potential for meat and also crop production lies in the vast areas of the humid tropics with year-round warm weather, high rainfall and deep porous soils, provided that the correct management is always applied.

The principal meteorological factors which may affect the quantity and quality of milk are: temperature, humidity, wind velocity, radiation. Adverse meteorological factors can influence milk production by alteration of the animal's thermal balance, water balance, energy balance and behavioural activity. Hot humid summers have a depressing effect on milk production and the butter-fat contents decrease. An increase in wind at temperatures below the comfort zone may hinder milk production. Environmental pollution of air, water and the soil by animals or industry may influence quantity and quality of milk.

Weather and climate affect wool growth and quality and can have an effect on the thermoregulation of sheep. Brown (1971) pointed out that wool productivity increased in general with latitude. Brown (ibid.) thinks that the decrease in productivity of wool is due to lack of availability of food which in turn can be related to climate. A hot environment can also decrease food intake and diminish the wool grade. If the site is protected from cold then cold spells do not appear to affect wool growth. Ultraviolet light degrades the tips of wool fibres causing them to break off during processing. The amount of vegetable matter and dirt that gets into the wool affects the quality. When six per cent of the wool clip is contaminated with dirt, grass burrs, etc. the quality cannot be assessed as high. The presence of moisture on the skin of the sheep over several weeks causes a bacterial dermatitis, viz. 'fleece-rat', which causes matting and staining of the wool fibres. The problem in India can be economically serious; two shearings per year are necessary to separate wet season and dry season wool clips.

Fly-strike can be a serious infestation in sheep and outbreaks can be particularly severe after wet weather; if fleece rot is present, fly-strike under the fleece can significantly reduce the value of the wool. After shearing sheep may die from a spell of cold wet weather if they are not sheltered, but they can survive the heat at this stage.

Air temperature, humidity, wind and light all affect the body temperature and comfort of poultry and therefore the egg production. The thickness of egg shells is decreased by heat and high humidity. The College of Agriculture in the Philippines achieved a ten per cent increase in growth by feeding broilers at night compared to the normal day-time feeding.

Models have been devised to represent individual animal responses usually in terms of thermoregulatory or other physiological subsystems as they respond to energy flows in the animal-environment system. A heat stress usually depresses appetite and consequently the production of items such as milk, eggs and meat is depressed. Temperature thresholds exist above which beef cattle, hogs and poultry do not fully recover either growth or food conversion; however, below such upper limits these animals are able to both recover growth lost during moderate heat stress and to convert food more efficiently after relief from heat stress.

Production responses of cows (milk), pigs (meat), poultry (eggs and meat) as a function of climatic factors have been combined with the probability of occurrence of weather events, developed from climatological records, to make predictions of production losses by Hahn and Osburn (1969), Morrison et alia (1970) Hahn (1975) Ibrihim et alia (1974). Hahn and Osburn (loc. cit.) have plotted the expected milk production losses in kg per cow with a normal daily production of 30 kg per cow for the summer season. Appropriate water and food supplies were assumed to be available along with shelter from the radiation load. The seasonal loss varied from 450 kg in the tropical parts of USA to only 50 kg in the higher latitudes. Morrison et alia (loc. cit.) found that for shaded 70 kg fattening pigs subjected to normal summer weather, productivity varied from 95 per cent of the optimum growth in the higher latitudes to only 70 per cent of the optimum growth in the tropics. Hahn (loc. cit.) found that expected egg production losses in Missouri for shaded laying hens subjected to normal summer weather, varied from 86 per cent of the optimum in the west to 95 per cent of the optimum over parts of southern Missouri. Hahn (1974) used the naturally varying climate of Columbia, Missouri, to compare the effects of year-to-year climatic variation on the predicted decline in milk production for cows with a normal level of production of 30 kg per day. The coolest summer showed an expected decline of 40 kg per cow whilst the hottest summer showed the expected decline per cow to be 250 kg. Maunder (1974) has used weighted indices of water deficit to predict monthly dairy production.

A derived Temperature Humidity Index (THI) can be obtained from dry bulb $(t_{db})^{\circ}C$, and dew point $(t_{dp})^{\circ}C$ according to the following relationship:

$$\mathrm{THI} = t_{db} + 0.36\, t_{dp} + 41.2$$

Berry et alia (1964) have related the milk production decline (M dec) in Holstein dairy cows to the Temperature Humidity Index (THI) as follows:

$$\mathrm{M\ dec} = -1.075 - 1.736\,\mathrm{NL} + 0.02474\,(\mathrm{NL})\,(\mathrm{THI})$$

where NL is the normal level of production in kg per day.

A decline in production at THI values of 70 and above for cows producing at least 15 kg per day is indicated from the previous relationship which is mainly based on laboratory results. Although the most pronounced decline in lactation at 40°C was shown by the Holstein cow, yet the milk yield from this cow was still as high or higher than other cows. Ansell (1976) observed that lactating British-Friesian dairy cows could maintain both yield and body condition in a hot climate such as Egypt, when fed a suitable ration. The consumption of the ration during hot summer months took considerably longer. When night-time temperatures are low enough to permit dairy cattle to recover through dissipation of accumulated body heat, they are able to withstand relatively high daytime temperatures. Compensatory growth can follow a suppressed growth period caused by heat stress when animals voluntarily reduce food intake to maintain homeostatis. In fact, within certain limits the ability of growing animals to recover from adverse climates is considerable. A yield forecast can be made allowing for normal climatic variation using THI or a climate control can be used, as reported by Hahn (1976); the emphasis on shelters is shifting from being a mere safeguard against chilling winds and the radiation load to a productive function through the provision of heating and cooling, so creating optimum conditions for maximum productivity in all latitudes. Obviously, the latter system has to be subject to cost-benefit considerations.

Livestock reproduction can be quite adversely affected by hot weather, particularly severe or prolonged exposure to severe heat, e.g. 40°C for 12 hours can adversely affect spermatogenesis in bulls. Likewise with cows, a negative relationship exists between body temperature at breeding and subsequent conception rates.

Ingraham _et alia_ (1974) found the average THI of the second day prior to breeding to be closely related to conception rates. Hahn (1976), using Ingraham's results, related average rectal temperature (RT) to THI and conception rates (CR) to THI for dairy cows in summer conditions. The equations used were:

$$RT = 29.3 + 0.13\ (THI)$$

$$CR = 388.3 - 4.62\ (THI)$$

The latter equation would be helpful in estimating annual yield figures assuming that water availability, pasture production and potential disease and pest patterns were taken into account.

Christianson (1978) represented cumulated stress (C_S) in terms of food intake deficit as a function of the departure of the average daily temperature from the upper end of the thermoneutral zone (T_{nu}). The latter is related to the weight (W) kgs of the pig as follows:

$$T_{nu} = 34.7 - 0.033W^{0.72}$$

Comulative stress (C_S) is also related to the weight (W) of the pig assuming a food energy level of 13000 kJ per kg.

Compensatory growth after heat stress, with respect to animal growth performance, can be related to a biological accumulation index in the form of a dimensionless compensation rate (Cr) where

$$Cr = 0.35\ (1 - \exp\ (-0.347\ C_S/W^{0.3}))$$

A book-keeping technique has been used to assess Cr whereby calculations are made on a day-by-day basis so that weight-gain deficits are added during heat stress and subtracted during non-stress periods when compensatory weight gain occurs.

A climatological assessment of disease potential would be a beneficial aid to livestock management. A tabulation or chart of significant periods, say three days when radiation was an absolute minimum, i.e. overcast sky and relative humidity remained over 60 per cent, would be a useful management aid in the control of foot and mouth disease. Similar tabulations for other diseases or pests would assist in yield assessment.

During heat stress sheep have a restricted food intake at 32°C or above. As with most cattle, sheep perform best with an average daily temperature range between about 4°C and 24°C provided relative humidity does not become extreme; the range could be reduced by about 3°C where sheep are exposed to a high radiant heat load. Newly born and recently shorn sheep are susceptible to hypothermia when exposed to a combination of rain, low temperatures and windy conditions. A nomogram prepared by the Bureau of Meteorology Australia (1982) can be used as a management aid to ensure shelter whenever adverse weather is forecast.

Making use of econoclimatic models Maunder (1979) used differences in the weather between seasons to predict the national wool production in the subsequent season.

2.4 Data requirements for improving livestock production

Data bank

The basic meteorological data stored in the data bank represent a summary of the climatic resources of a country. In addition to the fundamental meteorological data all relevant satellite information should be stored for future use. Satellite information provides areal surveys of elements, whereas traditional meteorological observations are geared to a point.

Real-time service

The provision of forecasts and warnings is essential to efficient livestock management. A knowledge of the overall current weather from bulletins of rainfall, etc. together with forecasts and outlooks for extended periods enable planning to be carried out regarding the provision of water, food, shelter, etc. Receipt of specific warnings of floods, bushfires, hot or cold spells, enables strategic measures to be taken to protect and save the lives of cattle, etc. An ongoing drought watch should be kept at all times and bulletins issued whenever serious or severe conditions exist. Using decile rankings it is often possible for the meteorologist to calculate the amount of rain needed to alleviate a drought and to assess the probability of the drought being broken in a given period. It is also possible to use deciles to estimate safe stocking rates on an area, water storage, soil state, etc. When the special meteorological requirements that foster disease or pest outbreaks are known then real-time values of such elements, together with predicted values, can assist management in control or eradication.

Agrometeorological data

In order to enable an interdisciplinary approach to improve livestock production, a compilation of the reaction of all livestock to significant meteorological parameters should be available in a special operational data storage unit. Apart from the specific details of the effect of variation of standard meteorological events on livestock additional specifications could include items such as:

- All available statistics on water availability including underground storage;

- The optimum climate, including allowable tolerance for maximum productivity for each species of livestock;

- A list of weather-promoted diseases and pest outbreaks to which livestock are susceptible, together with values which would indicate an outbreak;

- All relevant production figures which would enable cost-benefit analyses to be carried out.

Models

Relevant mathematical models and empirical physical relationships should be assessed. A facility should exist so that the primary information stored in the data bank can be readily programmed to produce probability charts or indices which could assist management to improve productivity and provide forecasts of probable yields, etc.

Seasonal loads of extremes of cold and heat stress can be evaluated beforehand using the data bank and appropriate models. The likely effect such extremes would have on productivity and reproduction can be predetermined thus assisting in deciding which type of livestock would be best suited to a particular area.

Climate control

Models are available, which in conjunction with the data bank can indicate whether, from a cost-benefit point of view, livestock should be managed in the open, with partial shelter or with an entirely controlled environment. Modification of the microclimatic environment may be necessary if bushfire danger is a threat. Appropriate models can be operated to assist in decisions where the quality of the product is a premium or where an optimum mix of quantity and quality is desired.

Probability charts

As water is fundamental to primary food production for stock and for the secondary production of livestock, probability maps of all aspects of water availability should be readily available to the manager. Other probability charts such as disease and pest outbreaks should be based on the frequency or return periods of meteorological elements which sponsor outbreaks.

Transport, markets, etc.

The proximity to transport and markets is a primary consideration for a manager. Data on the storing qualities of livestock products and the cost associated with transport to market, need to be considered when assessing the profitability of a venture. If stock are to be sold 'on the hoof' then the cost of transport and the condition in which the stock will arrive at market may be a factor of prevailing meteorological conditions.

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START INDEX

3. DETERIORATION OF PLANT COVER AND ITS ECOLOGICAL CONSEQUENCES*

Introduction

Desertification is the spread of desert conditions to neighbouring areas or the intensification of such conditions in the desert itself. In any such process a number of complex interrelated factors come into play, in particular, those related to the effects of climate, soil, flora, fauna and man.

In certain circumstances these factors can precipitate or intensify a series of events that can lead to deterioration of the vegetation and soil in a locality and surrounding areas. This process can directly affect the local production system, which is already insufficient and of low yield by extending the diminution of plant cover to agricultural land, with consequent erosion and the formation of dunes. Indirectly, it causes a large decrease in human settlement or the population migrates because of the area's restricted capacity to generate income and to provide appropriate sustenance for man and food for his livestock.

From time immemorial the climate, large-scale orogenic movements, encroachment of the oceans, and man have been considered to be the factors most likely to lead to aridity and desertification.

Certain phenomena related to these factors are still unpredictable in both nature and frequency, for example, variations in climate and large-scale orogenic and ocean movements. Others, for which man is responsible, have been brought about by inapt or abusive use of the land which has in general been used without the knowledge required to conserve its nutrients, covering and richness. The factors man and climate, considered from an ecological point of view, are by no means independent and have been particularly important in the progressive desertification.

It is obvious that one of the major reasons for land degradation is man's inappropriate use of plant cover. It is necessary to know how vegetation helps to conserve the soil and how to identify the signs and processes of desertification, as well as what happens when resources become depleted or exhausted.

Soil is conserved by the plant's root system which fixes the soil, and by the plant as a whole reducing wind velocity and hence erosion; likewise branches, leaves and roots dampen the impact of falling rain so that the rain falls softly and slowly on the land and does not drain away rapidly. There is therefore less erosion of soil particles on and below the surface because the vegetation itself prevents particles from being washed away by the rain. Furthermore, when plants die their branches, leaves and roots disintegrate and decompose, becoming incorporated in the soil as organic matter, thus helping to improve the soil structure and its capacity to absorb water.

Vegetation in desert zones is characterized by a small mass appearing on the soil surface, which is only partially covered, and by low productivity and palatability. Being part of a fragile ecosystem, which is particularly vulnerable and inflexible, the plants take a long time to recover and their lifespan, though already brief, is much affected by problems of weather and climate, as well as by phenomena induced by man (overgrazing, fire, woodcutting, salinity, erosion) and a series of socio-economic factors.

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*by M. Garabatos (Argentina)

3.1 Agrometeorological factors relative to pasture degradation

Mabbutt (1977) states that "two major factors are certainly involved in desertification, namely stress of an arid climate reinforced by periodic drought, and the impact of man's use of desert lands".

He continues: "... there are those who place greater emphasis on one of these (factors) to the virtual exclusion of the other. A true appreciation of the problem and any effective remedial measures require careful consideration of both, but it must be underlined that they are not independent factors, for instance, unwise cultivation of marginal lands can increase wind and water erosion. This very interconnection presents a major problem in analysing the evidence.

"Two other sources of difficulty should be mentioned. The first is the lack of climatic records of any length in desert areas where recording stations still tend to be widely spaced, and, associated with this, the lack of systematic measurements of vegetation cover. The second, which is exacerbated by the first, is the extreme variability of desert rainfall from year to year, or over runs of years, and with this a marked fluctuation in the extent of effective aridity."

It is interesting to note further that "the climatic desert margin advances in dry years and retreats in relatively wetter periods. This renders 'averages' meaningless, and makes it difficult to identify longer-term trends against a background of shorter-term climatic cycles of marked amplitude".

Mabbutt also states that "analysis of the climatic factor in desertification at the regional scale only is quite inadequate; as a control of plant growth in deserts, climate must be studied at the scale of its interaction with the ground surface and particularly as part of the soil/plant/water/atmosphere complex. It is more convenient to do this in the context of desert ecosystems".

In his report Mabbutt raises four questions concerning the uncertainty that reigns regarding the role of climate in the problem of desertification.

The first question is whether we are experiencing climatic change or climatic fluctuations. As Mabbutt puts it:

"The first question has arisen in view of evidence that, since the 1950s and 1960s, shifts in the position of the zonal pressure belts in association with cooling higher latitudes, particularly of ocean water, have brought the subtropical high-pressure systems somewhat closer to the equator and have limited the latitudinal range of the intertropical convergence, thus reducing rainfall in the desert high-pressure zone, particularly on its equatorward fringe. It is suggested that the pattern has continued into the 1970s on a world scale, including the southern hemisphere deserts, and that the change may persist for a few centuries. Some of those who presage a long-term change of climatic regime point to evidence that former changes from pluvial to non-pluvial periods have been achieved over a century or so.

"On the other hand the magnitude and duration of the Sahelian drought, which broke in 1974, was not unprecedented in climatic terms, despite the short records. The drought of 1913, for example, was probably equivalent, and may have caused greater loss of human life, if not of animals.

"At this stage, particularly in the light of the recovery of rainfall in 1974 and 1975, it is advisable to regard the Sahelian drought as part of a climatic fluctuation with a period of the order of one or two decades, such as is likely to occur once or twice in a lifetime. In any case, the consequence of a longer-term trend to aridity would merely be that such fluctuations would be more certain to recur, probably with increasing intensity. It is not necessary to see the Sahelian drought of the 1970s as a special manifestation of the onset of a changed desert climatic regime, and it would be mistaken in considering remedial measures insofar as its human consequences have their origins in human activities over the preceding years.

"Consideration of longer-term variations of climate raises the question of the time perspective in which the problem of desertification is to be assessed and combated. It is commonly accepted that this must be of the order of a generation or two, namely twenty to fifty years. However, evidence of longer-term climatic changes may be relevant in considering the status and inherent stability of desert landscapes, and particularly the relative importance of natural and human causes of desertification over historical time."

The second question is whether man-induced changes have provoked a significant recent deterioration in desert climates. Mabbutt continues:

"A number of claims have been made that the desert climatic regime may have worsened because of man's degradation of desert ecosystems. These postulated positive feedback mechanisms include: (a) increased dust and other aerosols in the upper atmosphere; (b) diminution in the number of organic ice nuclei in the atmosphere through devegetation, thus reducing the rainfall; (c) increased albedo of degraded desert land surfaces, causing lowered surface temperatures and diminished convectivity and associated rainstorms; (d) increasing atmospheric concentration of CO_2, causing a general rise in temperature through its absorption of infra-red solar radiation (greenhouse effect).

"The direction of influence of some of these factors, notably increased dust in the troposphere, remains the subject of controversy; some, such as dust and CO_2, may counteract each other. Others (albedo effect) have been incorporated effectively into dynamic models of atmospheric circulation and precipitation. At this stage it would be realistic to recognize that some of these factors may have accentuated desert climatic stress, but are most unlikely to have been prime causes of recent major droughts. It is also most likely that more direct physical consequences of some of the postulated causes, notably the effects of surface degradation on microclimate, runoff, infiltration and evaporation, may have been immeasurably more important than any macroclimatic changes."

The third question is whether long-term weather forecasting will make it easier for man to cope with the uncertainty of desert rainfall in the forseeable future.

"The existence of rainfall cycles in desert climates is well authenticated. Of these, the biennial and five-year cycles constitute the immediate variability against which any desert land-use system must operate; their effects tend to be absorbed in various ways by flexibility, resilience, or reserves in such systems. More significant are the fluctuations with a periodicity of one to two decades, which are expressed as runs of wetter and drier years. It is not merely that the decadal fluctuations include more extreme rainfalls, they also interact more significantly with factors affecting systems of desert land use, for instance, world commodity prices and disease or breeding cycles in stock.

"Unfortunately rainfall fluctuations of this periodicity are not sufficiently regular to form a basis for predictions of seasonal rainfall, and certainly not a basis for short-term agricultural planning.

"Possibilities of seasonal forecasting may rest in:

(a) Establishment of climatic teleconnections; for example it has been claimed that a forecast for an African rainfall in any year can be made from the pressure anomaly in the previous (northern) autumn in a crescent extending from the Ganges through the East Indies into Central Australia. These may provide a rough basis for general agricultural planning within the next few years, particularly where the correlation exhibits a time lag of some months.

(b) The establishment of fundamental dynamic models of atmospheric circulation, incorporating known factors such as equatorward temperature gradient and ocean temperature anomalies. Current developments can be described as promising in their elucidation of the mechanisms and contributory factors involved, but reliable forecasting models may lie one or two decades ahead.

(c) On a shorter term and more local scale, the use of satellite imagery to monitor the movement of air masses and storm cells; at this stage the approach is limited to forecasts a few days ahead. It has uses in locating areas of incidence of patchy rainfall, with consequences for the use of desert pastures, for it should be emphasized that, in the deserts proper, rainfall tends to be quite localized in space as well as in time, and rain forecasts must always incorporate this geographical uncertainty."

The fourth question is whether man can ameliorate the desert climate to his advantage.

"The amelioration of desert climate on a regional scale has been an objective of many schemes. Some of these have involved the formation of large inland water bodies to act as evaporative sources of local rainfall through the diversion of river systems. Fortunately, perhaps, the cost of such schemes has prevented their implementation because theoretical testing has strongly indicated their uselessness. Schemes of this type overlook the fact that the existence and location of the world deserts are determined by the global atmospheric circulation, for they are high-pressure regions of subsiding and therefore stable air on an immense scale. Subsidence may locally be reinforced by relief, whilst the likelihood of rainfall may be further diminished by distances from the oceanic sources of rainfall or by the existence of cold littoral currents, inducing unfavourable temperature gradients inland. None of these global factors will be modified by the existence of a local water body, as witness the many deserts bordering the oceans.

"Other schemes for the modification of desert climate on a regional scale have included tree planting and the creation of a so-called 'oasis effect'. Although beneficial at the local climate scale, these can be demonstrated to have no effect on regional rainfall.

"Rain-making through cloud-seeding has so far been employed in sub-humid rather than in arid regions, for rainfall can be induced only where cloud and humidity conditions are favourable, and this is least likely in a desert. The mechanisms involved also indicate that rain induced to fall locally would be at the expense of the probability of rain in a much larger contributory area. The possibility remains, however, that rain might be induced locally with advantages, for example over a potentially favourable pasture type or in a harvested drainage catchment rather than in a less productive or uncontrolled area. Significant success in artificial rain-making has yet to be achieved in any arid area, and the costs of the operation might in any case exceed their benefit.

"It appears to be realistic to assume that, in the period under consideration, desert lands will be used against the same climatic difficulties and uncertainties as in the past, and to plan future use on the basis of an understanding of the risks and limitations set by existing climate, rather than in the expectation of more certain or improved climatic conditions."

3.2 Natural and socio-economic factors in the diminution of vegetative cover

Overgrazing

In most cases, overgrazing results from the uncontrolled size of herds which considerably exceed the capacity of the available vegetation cover to feed them.

Under such pressures as overgrazing and the trampling around livestock watering points and enclosures, the biomass gradually diminishes. The selective effects limit productivity and are brought about by excessive browsing on shrubs and changes in the structure of the vegetation when the most palatable species are supplanted by less palatable plants; perennials give way to annuals and plants that are most resistant to progressive desertification take over from those that are weaker.

Consequently the land has less cover and progressively lacks protection against the vagaries of the weather which deteriorate it sooner or later resulting in problems of dessication, weakening, erosion and the formation of crusts. It is then difficult for water to penetrate and for vegetation to germinate and grow. These conditions are accentuated by drought and lead to large-scale erosion which in turn disturbs and removes the soil leaving crevasses and dunes - infallible indications of the approaching transformation into desert.

Fire

Man can initiate and continue degradation of the vegetation by indiscriminate use of fire. Surface temperatures of around 400°C can generate fires and destroy not only plant cover - firstly trees, then bushes and finally pastures - but also micro-organisms, thereby going on to upset the already weak and unstable biological equilibrium found in desert ecosystems.

This destruction can extend to soil humus and the organic matter in the topsoil. When this occurs the living surface, which in desert zones is extremely thin and highly vulnerable as well as being slow to recover, shows signs of the disequilibrium in the ecological system, disintegration of the colloids, together with edaphic granulation, and destruction of the best system for basic interchange. This leads to leaching of the useful soluble components and erosion which increasingly drains soil susceptible to desertification. If there is prolonged drought at the same time, degradation of soil deprived of its plant cover by fire is accelerated until the effects become virtually irreversible.

It may be concluded that although fires appear beneficial, controlled burning does not necessarily ensure complete effective regrowth or resowing, which depend upon the effects of the fire and the subsequent weather conditions, and these are risks which man cannot yet control.

Woodcutting

The destruction or uncontrolled use of trees, in general for agricultural or industrial purposes, is frequently another cause of destabilization in desert ecosystems which, as already mentioned, are vulnerable and slow to recover.

Elimination of wood cover carried out haphazardly leaves the naked and totally unprotected soil at the mercy of climatic instability unless corrective measures are taken straight away. These processes can lead to practically irreversible degradation in the long or the short term.

It is necessary to bear in mind the importance of vegetation, including trees, bushes and pastures, in the settlement and improvement of the soil, in the interception of rainfall and the mitigation of strong winds, thereby contributing to improvement of the water supply and the diminution of erosion. These advantages are lost when woodcutting does not ensure replacement of the plant cover and replanting.

Salinization

Soils also deteriorate through salinization, which can occur in semi-arid and even humid regions but is particularly destructive in arid zones, especially those with a low rainfall of generally less than 100 mm. These are highly vulnerable desert regions where the more or less constant lack of extensive rainfall and permanent high evaporation facilitate a fairly rapid increase in the level of basicity of the soil.

As a result these soils show an alkaline or neutral reaction on the surface and an alkaline reaction further down. If drainage is limited and if the evaporation becomes excessive, the soluble salts - mainly of sodium - tend to accumulate in the surface layers and to produce saline salts. Concentration of the latter can become so high that they threaten the growth and even the life of the plant cover. The plants die following an increase in osmotic pressure which becomes intolerable for the plants' roots and does not allow the absorption of water and nutritional elements.

Saline accumulation in such poorly drained soils can be due to their own composition, subterranean sources or irrigation channels misused by man. The problem becomes more acute when saline water is used for irrigation, particularly when it comes from rivers, whose saline content increases when stored in dams due to the evaporation of the water.

The removal of desert vegetation in any of the above ways gives full rein to physical degradation processes in the desert ecosystems. For example, these may take the form of crevasses caused by erosion, sand drift or dune encroachment owing to the existence of soil that is highly vulnerable because it has sparse or non-existent plant cover, leaving it without any protection or organic material to preserve its structure and capacity to absorb water. The result is poorly fixed soil of low consistency and moisture content.

Erosion can lead to considerable loss of valuable land. It can be a natural phenomenon taking place slowly and normally following a geological or habitual pattern, but when it goes beyond the norm it becomes accelerated erosion. This occurs on denuded or sparsely covered surfaces with no protection against changing weather, particularly insolation, wind, heavy rainfall, under adverse topographical or edaphic conditions such as surfaces with steep slopes and poor structural stability.

Water erosion can take place in sheets (the surface being removed in uniform layers), in gullies accompanying or following the sheets when the intensity of the rainfall increases, or in watercourses, i.e. in passages of concentrated rainfall (ravines or gorges).

Wind erosion is peculiar to arid and semi-arid areas and rarely occurs in humid ones. The changes it produces are characterized by abrasive effects on the moving material, the extent depending on the state of the soil and the wind speed. The separation of soil particles followed by their transportation are typical of this phenomenon. The particles carried by the wind can cover distances of hundreds of kilometres suspended at heights of from a few metres to 1 000 m, falling slowly as the wind velocity decreases or they are removed from tbe surface by the rain. These effects are increased by persistent drought conditions or by man's mismanagement of the land.

The wind can give rise to a certain type of sand formation of small or large relief, i.e. in the former case crescents and in the latter dunes. Changes in wind direction and velocity and the presence of vegetation can alter these typical forms somewhat but not to any significant extent.

The balance of arid ecosystems, especially deserts, is probably destroyed when for the first time man ploughs the earth to plant seed or grazes his livestock on the sparse fragile vegetation.

Subsequently negligence, or more frequently lack of knowledge and insoluble socio-economic problems, lead to abusive uncontrolled use of the plant cover. When this happens, without realizing it, man sets in motion a land destabilization process that is prolonged and accentuated whenever the population of a settlement exceeds the available resources in the area. Exaggerated competition for scarce natural resources, frequently associated with uncontrolled grazing, woodcutting, salinization, erosion and the formation of dunes, leads to the deterioration of large areas until the way is left open for desertification.

At present, many of the causes of desertification are better understood and, although there is still a lack of knowledge concerning some of them and their relative importance, the experience gained shows how important it is to be aware both of the rapidity with which productivity in arid zones, particularly deserts, can disappear and of the difficulty of recovery from the agricultural point of view. It is necessary to recognize signs of desertification in sufficient time before the deterioration of the soil and plant cover have reached such a high level that, for agricultural and economic reasons, recovery is almost impossible.

Furthermore, one of the indirect causes of ecological deterioration in desert regions is to be found in the numerous socio-economic, political and cultural factors governing the living conditions of the inhabitants. They lack protection, do not have the opportunity to become owners of their land and water resources, do not enjoy adequate housing, liberal credits, health care and education for their families nor do they receive the orientation necessary to improve techniques of conservation and utilization of resources in such regions.

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4. NON-IRRIGATED FARMING (DRYLAND AGRICULTURE) IN ARID AND SEMI-ARID AREAS*

4.1 Methods of assessment of actual and expected agrometeorological conditions for non-irrigated farming

The production of cultivated crops in any area is dependent on many factors. Some can be influenced by management decisions and some are beyond the control of man. Major changes or development plans for the long-term strategic use of land involve outlays of capital far greater than the operational costs in any one season. Therefore, such changes or plans must be based on a sound appraisal of the climatic advantages and climatic risks.

For dryland agriculture in semi-arid and arid areas to be successful, certain basic conditions must be recognized. The most successful crops have a moisture-use pattern that corresponds to the maximum rainfall periods. The rainfall storage efficiency of coarse textured soils is usually less than 30%; so the crop should efficiently use rain as soon as possible to minimize evaporation of soil water. The crop must not only survive short drought periods, but be able to respond when additional rains are received. If the crop is established after the rainy season it should have a short growing season.

The use of stubble mulch practices will increase rain water storage efficiency by reducing runoff and evaporation losses. In areas that do not grow residue crops, shallow tillage of the soil after a rain as soon as the soil surface starts to dry will help reduce evaporation losses.

Most semi-arid dryland cropped areas are characterized by wide variation in annual rainfall. This means that the farming systems must be flexible to maximize crop yields on the limited rainfall. Some years will be too dry to grow any crop. In some years the rains may come too late to grow a long season crop, but a short season crop may be grown. Critical temperatures may determine the planting date and may limit the crop depending on its maximum temperature.

After summarizing 15 years of dryland studies at Akron, Colorado, Mattice (1926) concluded that dryland farming in an area receiving only 450 mm of rainfall was decidedly precarious. Sixty years later we see extensive dryland agriculture in the 450 mm area and development of cultivated agriculture in a 360 mm rainfall area. Cultivation of sandy soils in low rainfall areas is possible, but the risk must be recognized.

The science of agro-climatology aims at the interpretation of the climate or the expected type of climate over a decade or so in terms of the most suitable form of crop production. Comparison of the climate in areas where a crop is grown, and where the highest yields are obtained, with areas growing the same crop, but having a different climate, can give useful information regarding the weather limitations and optimum growing conditions.

Rainfall

As annual rainfall decreases the selection of crops and management schemes becomes more limited and critical. Moving from the sub-humid to the semi-arid or arid areas, selection will be limited to those crops that will survive and still produce under increasing moisture, heat, and soil stress conditions. Excluding the

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cold arid regions, as rainfall decreases, the air and soil temperature increase, subjecting plants to additional environmental stress.

All agricultural crops require water to grow. To produce maximum yields the distribution of moisture during the growing season may be equally or more important than the amount received. The most successful crops are those with moisture use patterns that follow or slightly lag behind the normal rainfall pattern. For most crops the availability of soil moisture at seeding is critical. Without sufficient moisture to germinate the seed and supply the minimum crop needs, no cultivated crop can survive. After crop establishment, the reproductive development is the second critical stage. In the grain crops seed filling is a third critical stage. The rainfall storage efficiency in sandy soils in semi-arid regions is low. More efficient use of available moisture will result if the crop can begin utilizing the soil moisture soon after a rain, and the crop growing season is short (Table 10).

Wind

In most semi-arid regions wind has played a major role in the geomorphology and continues to influence agriculture because of its effect on soil erosion and growing plants. Exposure of crop seedlings to wind-blown sand can reduce survival and crop growth (Table 11). Excessive wind movement coupled with high air temperatures and low humidity can desiccate both irrigated and dryland crops. A few hours' exposure to high evaporative demand during critical growth stages can lower crop yields from near potential to near failure.

Humidity

The drying ability of the air will influence the crop selected, planting date, and crop yields. Even though the soil is wet, if the humidity is low and temperatures are high, considerable environmental stress can be placed on the crop to maintain its leaf temperatures below the critical level.

Temperature

All crops have an optimum temperature at which plant growth is maximum. In semi-arid regions the minimum temperature for seed germination and growth may not be as important as the maximum but will influence the planting date of most crops. Air temperatures during the growing season are important because of high-temperature-induced stress. Some crops adapt to temperature stress by curling the leaves, dropping leaves, or abscissing fruiting forms.

Solar radiation

Solar radiation is the driving force behind all stress factors. The impact of high radiation may be reflected in increased plant temperatures or increased transport of a growth inhibitor from the leaf to the stem. The intensity of ultraviolet (UV) radiation is usually too low to damage proteins and nucleic acids in the cells of higher-order plants. In nature, direct UV injury is not likely to occur because of the plants' ability to tolerate reasonably high levels of UV (Levitt, 1972).

4.2 Agrometeorological forecasting of crop development and yield

The need for good crop yield models has long been recognized. But the extreme variability of weather within a short period of time has made the development of good dryland crop-yield models extremely difficult. Agriculturalists would like to have accurate forecasts six to nine months in advance. This would enable them to recommend practices that would reduce the impact of droughts and more effectively control erosion.

Without good long-range forecasts, the next alternative is to study previous climatic patterns and agricultural records and attempt to develop models to describe the relationships. Hooker, in 1931, reported that crop-yield forecasts fell into two main groups: those which predicted the recurrence of good and bad crops in cycles, and those which computed the actual amount by which yield was improved or which was damaged by weather during or shortly before the growing period. Models by Moldenhauer, Mattice and Kincer are examples of models relating weather and crop yields. Each model has advantages and the selection of a dryland crop-yield model will depend on the intended use of the data and the precision required. These models will provide information on potential crop yields but will not provide information on crop response to stress during the growing season.

Munn (1970) summarized similar studies and concluded that "statistical analysis may lead to physical insight into the relative importance of various meteorological factors, and may assist in the selection of the most appropriate averaging and lag times". For example, it has been found that for early tea (April-June) in the Assam Valley in India, mean temperature and the logarithm of rainfall, each with a three-month lag time, were significant predictors. For the main crop (July-September), but not the late one (October-December), the temperature and logarithm of rainfall in the January-March period were significant predictors. For corn in Illinois (USA); August mean temperatures were inversely correlated with yield, but rainfall during the time period 1955-1963 was not a yield-limiting factor. For a drought time-period the results may have been different. For winter wheat in the black-soil regions of the USSR , it was found that available soil moisture and sprouts per square metre was positively correlated with yields. For rice in Northern Japan, a positive relation was found between yields and July-August temperatures. Crop failures were noted only in cold summers. For areas further south this meteorological element might not be a limiting factor.

These studies all illustrate the importance of interpretation and the expected use of the results. A more complete analysis is possible when the results are viewed by scientists from various disciplines. For example, a gradual decline in crop yields over a 20-year period may be viewed by engineers as evidence of erosion, by soil scientists as evidence of reduced soil productivity, by pathologists as evidence of increased soil diseases, or by entomologists as evidence of an increase in insects.

Most long-term data sets do not include all the measurements necessary to determine why yields have changed. If they increase, we give credit to technology. But if they decrease, the factors responsible are "not evident"; at least we seldom say it is the lack of technology.

Forecast of a dry period would enable the farmer to plan his cropping system to take advantage of rainfall received during the growing season. Crops growing in semi-arid areas will be subjected to varying intensities of stress each year. The recent models of Ritchie, Hanks, Jensen, Rasmussen and Hanks, Burt et al., FAO, and Quisenberry and Baier are examples of models that compute the response of crops to daily or short-time stress. Insufficient soil moisture at planting may prevent the production of crops that year unless a short-season crop is planted after rainfall is received later in the growing season. For example, dryland cotton at Big Spring, Texas is normally planted between 1 May to 15 June, but the lack of planting moisture durin this time period could mean that millet, guar or sunflowers might be planted between 15 June to 15 July if good rains are received.

In the absence of accurate long-range weather forecasts, the relationship between preseasonal rainfall and crop yields will provide information on expected yields. Previous analysis revealed that 127 mm af preseasonal rain was necessary to offset evaporation losses and increase soil-water storage (Moldenhauer). Soil-water storage efficiencies are normally 30% of rainfall or less. If you subtract 127 mm and take 30% of the remaining rainfall, estimated cotton yields can be calculated as follows:

$$\text{Yield} = 160 + 2.653 \text{ (adjusted rainfall)}, \; r^2 = 0.53$$

The yield-rainfall relationships are specific for Big Spring, Texas, but the same technique could be used wherever the data base is available. For Big Spring, the growing season is 220 days, and temperatures are sufficient to meet the requirements for maximum production of cotton. The best crop yields are in years with good soil moisture at planting time and good distribution of rain during the growing season. A 50-mm rain six weeks after planting followed by another 50-mm rain four weeks later will give excellent cotton yields even if the annual rainfall is below normal. If production costs are such that at least 250 kg/ha of lint is the minimum yield that will be economically feasible, then at least 33 mm of adjusted preseasonal moisture (237 mm total) is required. If preseasonal rainfall is below this level, the farmer may have to grow a crop other than cotton or the farmer may elect to use a wider row-pattern, so each row has a larger volume of soil water. Cotton has the ability to extract soil water 60 to 80 cm on either side of the row.

The FAO model was tested on dryland cotton yields over a 38-year period to see if it could be used to predict yield-climatic relationships. Since preseasonal rainfall will influence the availability of water in the soil profile at planting, the beginning soil moisture was adjusted according to the Main rainfall as follows:

< 100 mm	RS = 30
100-150 mm	RS = 60
150-200 mm	RS = 90
> 200 mm	RS = 120

The rainfall values ranged from 48 to 335 mm, and the FAO Index values varied from 7 to 80. The linear regression equation for cotton yield = 17 + 5.3 (FAO index) gave an r value of 0.61. With an indeterminate crop like cotton, the plant can respond to mid-season rains. The FAO index will not increase once it shows the soil water has been depleted, even if the remainder of the growing season had adequate water. If an indeterminate-type crop is being tested, an additional term may be required to account for the changing crop-yield potential when mid-season rains offset an early-season drought.

The daily soil water budget model (Baier, 1966) utilizes standard meteorological data to estimate soil water use by layers, but may provide more data than normally required to evaluate dryland crop yields on a large-area basis.

If the intent is to use the model results to aid in making management decisions, the simplistic statistical models may be best. Normally, decisions must be based on the present conditions and the most probable forecast of future conditions. A team consisting of agrometeorologists, agronomists, and engineers would be helpful in selecting the optimum model and in interpreting the results.

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TABLE 10

Agrometeorological requirements of major rainfed crops in arid and semi-arid areas

	Growing season days	Critical Temperatures Optimum	Min.	Max.	Plant growth	Water used per gm of dry matter gms	Photo-periods sensitive
		°C					
Millet	70-90	32	20	45	In Det.	310	SDR
Cotton	170-180	30	20	40	In Det.	568	DN (book) (18)
Winter wheat	> 120	25-30	0-5	37	Det.	577	LDR >12 (18)
Corn	210-260	15-35 60-95	10	38	Det.	368	DN, SDR
Sorghum	90-120	27-29 (16)	15	38	Det.	322	LDF (18)
Guar	120-145	30	20	45	In Det.	600	SDR
Sunflower	110-130	30-35	10	45	Det.	577	DN

LDF - long day favourable, DN - day neutral, SDR - short day required, LDR - long day required.

TABLE 11

Exposure time of 7 crops to a 1 500 cm/sec wind, sand flux of 0.5 gm/cm/sec, and plants 6 days old that will give 25, 50 or 75% survival (Fryrear, 1975)

Crop	Per cent survival		
	25	50	75
	Exposure time in minutes		
Cotton	18	12	7
Carrots	11	8	4
Onions	31	21	11
Peppers	12	8	4
Cabbage	15	10	5
Cucumbers	21	14	7
Southern peas	49	33	16

5. IRRIGATED AGRICULTURE IN ARID AND SEMI-ARID AREAS*

The water resources of deserts and semi-deserts consist of permanent and ephemeral surface runoff, groundwater and precipitation. They are used for irrigated agriculture and the water supply for industry, stock raising and the human population.

Over many centuries, the peoples of Central Asia have created large agricultural areas on what was once desert land by using river water for irrigation.

During the period of Soviet rule, the irrigation system in this area has undergone radical changes, mainly in the form of network reconstruction. Projects have also been developed to make full use of the runoff from the large rivers in Central Asia, namely the Syr-Darya (annual runoff 31 km^3) Amu-Darya (annual runoff 60 km^3), Murgaba, Tedgena, Vakhsha, Kashkadarya, Zeravshana, and others. This has made it possible to start reclaiming desert areas which had been neglected since irrigation was stopped centuries ago, as well as new virgin land.

Specialists have calculated that it is possible to obtain annually 1.5 million tons of cotton, 500 000 tons of rice, 330 000 tons of maize, 770 000 tons of milk, 200 000 tons of meat and other products from each million hectares of desert land on which irrigation has been resumed.

Irrigated agriculture is the most profitable type of farming in arid conditions.

Of great importance for the development of irrigated agriculture in Central Asia was the construction of the Lenin Karakum Canal in Turkmenistan, the establishment of new large cotton-growing areas in the Golodnaya Steppe and in the Karashinskaya Steppe in Uzbekistan and a number of other areas, thanks to the rapid introduction of irrigation.

Several tens of large land-improvement and water-management schemes have thus been set up, including the Amubukharsky power-driven canal, Karshinsky canal with six single-channel pumping stations, and the Bolshoi and Andizhansky and Bolshoi Namangansky canals, as well as the more than 100 km of the Karakum canal. The following works are now also in operation: the Chuisky by-pass, South Bolshoi Chuisky and Upper Dalverzinsky canals, the Takhiatashsky, Charvakasky, Uchkurgansky, and Samarkandsky water engineering systems, the Kattakurgansky, Karkidsky, Pachkamarsky, Khuazkhansky, Koptdagsky, Chardarinsky and Kapchagaisky reservoirs and a number of other works, many of which are unique in scale, technical design and economic value.

These water-management developments have provided for the requirements of irrigation and the reclamation of large areas of desert land in Central Fergana, uncultivated areas in the previously irrigated Golodnaya Steppe, Surkhan-Sherabadsky and Vakhshsky valleys, the lower reaches of the Amudarya river, the region of the Karakum canal and Karakalpakia.

During the Soviet period, the area of irrigated land in the desert parts of the USSR has been increased threefold.

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*by I. G. Gringof (USSR)

(Since the planned material for this section was not forthcoming, the chairman of the working group decided to replace it by available data on Soviet experience in this field drawn from (1) in the references for this section.)

This has permitted a considerable increase in the production of raw cotton in the Central Asian republics over the last decade (see Table 12).

Table 12 - Increase in irrigated land areas (in thousands of ha) and cotton production (in thousands of tons) in the Central Asian republics*

	1940	1965	1970	1975
Uzbek SSR				
Irrigated area	2276**	2639	2696	3006
Including land under cotton	924	1550	1709	1773
Raw cotton output	1386	3746	4495	5014
Turkmen SSR				
Irrigated area	454**	514	643	819
Including land under cotton	150	257	397	487
Raw cotton output	211	553	869	1078

* Narodnoe Khozyaistvo SSSR na 1974g. M., Izd. "Statistika", 1975
** Data for 1950

The use of new technology for irrigating desert land has made it possible to economize large quantities of water which were formerly lost through filtration and unproductive evaporation. Such technology includes anti-filtration linings and pipes in the irrigation network, closed horizontal and vertical drainage, regulating structures and modern irrigation means (sprinklers, underground and drop irrigation).

In some deserts, precipitation is an important source of fresh water. For example, the deserts in central Asia annually receive 100-200 mm of water in the form of rain and snow, i.e. 1000-2000 m^3 of water per ha. Nevertheless, a large part of this evaporates, although part also seeps into the soil nourishing the plants.

One method which is widely used now for replenishing the fresh groundwater is to store up the surface rainwater runoff from "takyr" (pool) drainage basins.

When there are no clayey takyr soils, artificial drainage areas are created using asphalt, cement and other coverings. It has been calculated that 1 hectare of artificial drainage area in the Karakumy can collect up to 700-800 m^3 of fresh water.

Groundwater discovered over large areas of the desert has also been widely used.

One important improvement of the water supply to scattered, small-scale users in the desert is achieved by distilling mineralized water (whether underground, sea, drainage, runoff water, etc.). Even in deserts, these water resources are practically inexhaustible.

Considerable success has been achieved in creating large distilling plants for municipal and industrial water supply. In Krasnovodsk (Turkmen SSR) and Shevchenko (Kazakh SSR), multiple-unit evaporating and adiabatic distillers have been constructed with an output of 13 200 and 15 000 m^3/day, whose fuel consumption has been considerably reduced, thus lowering the cost of fresh water. In 1973, the world's first atomic distiller was put into operation in Shevchenko, whose output is 120 000 m^3/day.

Work is under way to develop small distillers and sun and wind-powered distillers.

The planned transfer of part of the runoff from northern and Siberian rivers to Central Asia, Kazakhstan and the river Volga basin is of particular importance for bringing water to the deserts of the USSR.

The study of this vast problem has been included in work programmes by decision of the 25th Congress of the CPSU and the Soviet Government. The enormous amount of work involved in river runoff transfer, including the estimation of possible impacts on physico-geographical, ecological and socio-economic processes, requires a careful analysis of various factors. This analysis could be done with the most advanced research methods used in many branches of science. A wide-ranging programme of in-depth research is therefore now being undertaken by the scientific institutions of the Acedemies of Science of the USSR and the Soviet Republics, universities and research institutes sponsored by a number of governmental departments. This research covers the use of water resources and the redistribution of runoff over the USSR and, in particular, desert reclamation.

Examples of desert irrigation which have received international attention are those of the Golodnaya Steppe and the Karakum canal zone.

The Golodnaya Steppe is a desert covering more than one million hectares, and bordering on one of the largest sandy deserts of Central Asia, the Kyzylkumy. Irrigation in the Golodnaya Steppe was started even before the Revolution. However, the land reclamation was carried out in a primitive fashion and the land frequently became saline and was abandoned.

During the first years of Soviet rule, attempts were made to improve the existing irrigation systems and to develop new ones.

As irrigation progressed, it appeared necessary to construct intake dams on the river Syrdarya, then to regulate the river's runoff with reservoirs. The creation of dams made it possible to use the pressure head for producing the electricity needed for the irrigation pumping stations as well as the supply of domestic and industrial water.

The reclamation of the Golodnaya Steppe is a complex undertaking. Construction of the irrigation system is being carried out simultaneously with that of residential, industrial and cultural-domestic buildings on newly reclaimed land. The irrigation systems make use of the latest technology. Reinforced concrete is widely used for lining canals, flues, pipes, and closed horizontal and vertical drainage channels. The towns and villages are provided with water mains, drains, electricity and gas. Schools, hospitals, kindergartens, clubs, cinemas and other cultural or domestic buildings are being constructed. Factory farms have been set up as well as processing plants for their products. Likewise, trade and shopping centres have also been constructed. Trees have been planted in the towns and villages as well as along the roads and around fields (for protection).

The combined construction work and land reclamation in the Golodnaya Steppe has produced extremely favourable conditions for the survival of the population and for highly productive mechanized agriculture and the foundations have been laid for industrial development. This region has become an outstanding example of the transformation of the desert into a huge flowering oasis. Several thousand kilometres of irrigation canals, drains and pipes have been laid there as well as hundreds or kilometres of asphalt roads, electricity cables, gas pipelines and telephone lines, and some thousands of water engineering works have been built.

The modern irrigation systems make it possible to produce high yields of cotton and other crops through the efficient use of water.

The Lenin Karakum Canal is one of the world's most impressive structures. The total area irrigated by it is about one million hectares. It stretches from the river Amudarya to the foothills of the Kopetdag on the southern boundary of one of the largest sandy deserts of the Soviet Union, the Karakumy, its length being already more than 1 000 km. When completed, it will be 1 400 km long and will collect 800 m^3/s of water from the river Amudarya, i.e. 40% of its runoff.

Reservoirs with an impoundment of more than one km^3 have been constructed on the canal in order to regulate the free runoff during autumn and winter, when irrigation requirements are minimal. It is also intended to build reservoirs with an impoundment of 3.5 km^3 in the canal's top part.

The Lenin Karakum Canal performs a number of functions, including irrigation of fields and rangelands, water supply to towns, villages and industrial plants, fishing and shipping. Pumping stations are being constructed in the canal zone.

On the land which has been irrigated again after centuries of neglect in the lower reaches of the rivers Murgab and Tedgen, modern irrigation systems have been constructed with channels covered with anti-filtration linings, irrigation pipes, and covered drainage channels. This has made it possible to eliminate the harmful salts in the soil which had accumulated over a long period of desertification, and to produce high yields of cotton and other crops from the very first years of reclamation. The construction of towns and land reclamation have made it possible to populate the area quickly and to introduce agricultural cycles over large areas.

The construction of the Karakum canal and the development of irrigation in the Amudarya zone has made it possible to increase the collection of raw cotton during the period of Soviet rule in the Turkmen SSR by almost 17 times (from 70 000 to 1 078 000 tons).

Land has also been sucessfully irrigated and reclaimed in other desert areas, e.g. Khorezm, the lower reaches of the rivers Zeravshan, Kashkadarya, Surkhandarya, and the Fergan Valley in the Uzbek SSR as well as in Kazakhstan (Muiunkum, Mangyshlak, and the lower reaches of the Syrdarya, Chu and Ilr) where hundreds of thousands of hectares of desert have been turned into highly productive irrigated fields.

Table 13 shows the changes in the natural conditions brought about by irrigation and their positive or negative impacts, taking as an example the reclamation of desert in the Golodnaya Steppe. The changes are sub-divided into stable/unstable and/or controllable/uncontrollable ones. The stable changes are those which inevitably occur during irrigation and the unstable ones are those which may or may not occur, according to a combination of other natural factors. The controllable changes are those whose extent or positive/negative impact can be controlled by man through certain engineering and other measures whilst the uncontrollable ones are those which cannot be governed by man's intervention.

Table 13 - Types of interaction between irrigation and various natural conditions (after Dukhovny, 1980)

Change in natural conditions	Type of change	Impacts	
		Pos.	Neg.
Warming up of climate	Uncontrollable	+	
Change in type of wild vegetation		+	
Change in microcosm		+	
Change in fauna		+	
Reduction in wind force	Stable	+	
Change in microclimate		+	
Change in river runoff		+	-
Change in cultivated vegetation		+	
Reduction in unproductive evaporation		+	
Change in groundwater level	Controllable and unstable	+	-
Change in moisture in aeration zone		+	-
Change in mineralization of groundwater		+	-
Change in mineralization of river water		+	-
Change in moisture and physical properties		+	-
Change in salt reserves in the aeration zone		+	-
Erosion of slopes			-

The reclamation of the Golodnaya Steppe has convincingly shown that with the correct control system and organization of work it is possible to improve considerably the natural conditions and economy in former deserts.

A comparison of the climatic indices shows that during the transfer from virgin land to oasis, the air temperature in the surface layer drops by 2-5°C, the absolute air humidity increases by 5-11 mm, the mean monthly relative air humidity increases 2 to 2.5 times from 18-24 to 49-56% and the soil temperature drops 3.5-1.6°C. During the same transfer, over a period of three years, the wind speed drops 0.6-3.3 m/s. The radiation balance and potential evaporation also undergo sudden changes. As land reclamation progresses, potential evaporation drops by 10-12% during the first year, by 18-21% during the second year and by 20-25% in the third year(2).

When an area is properly drained, and an optimal land-improvement regime established (based on the proper selection of drainage depth and minimization of water requirements), it is possible, with a relatively low water consumption, to achieve stable control of groundwater levels, prevention of salinization of the soil, gradual desalinization of groundwater and soils and, most important, progressive increase in the land's yield. During the period 1961-1980, the area of strongly saline soil was thus reduced in the new zone from 36.4 to 6.8 thousand ha, and that of moderately saline soils from 21.2 to 11.6 thousand ha. The amount of salts removed annually varies on average from 12.6 to 29.6 tons/ha, for which the amount of water used on wash-out is 1.2-1.5 thousand m^3/ha. The system's coefficient of useful action was thus 0.78-0.81(2).

Agrometeorological research plays an important part in the reclamation of desert areas and, in particular, their irrigation. The range of topics covered by this research is extremely wide. It includes:

- Agroclimatic zoning of irrigated areas, with the aim of achieving the most rational spatial distribution of the main crops;
- Development of agrometeorological recommendations on the use of information when taking various agricultural measures (deciding on times and rates of sowing, formation of crop's architectonics taking into account the crop's microclimate, deciding on the times and rates of irrigation, deformation measures, deciding on harvesting dates, etc.);
- Development of methods for agrometeorological assessment and forecasting of crop development phases, dynamics of crop growth and formation and crop productivity;
- Development and improvement of methods for instrumental observation of the state of the soil and crops as well as crop productivity (surface, airborne and satellite instruments).

Results of such research have been published and are widely used for operational agrometeorological services with respect to irrigation (for cotton, lucerne, maize, rice, tobacco, vegetables, fruit, etc.) in the Soviet Union's deserts and semi-deserts.

A list of the main publications derived from agrometeorological research is included in the list of references for this section(3-14).

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6. OTHER PROBLEMS OF LAND USE AND MANAGEMENT*

The problems typical of the major land uses of arid and semi-arid lands have been reviewed in the preceding sections. Three other forms of desertification are mentioned here for completeness.

First, arid areas - as well as deserts - sometimes contain very large mineral deposits, and the huge mining operations undertaken to tap those resources may be extremely damaging to the environment. This is a serious problem, and considerable attention has been given, in particular in the United States, to the reclamation of such disturbed lands. Agrometeorology however has little to do with or to provide to mining operations: its role could become significant only in relation to revegetation attempts.

A second potential problem is due to certain forms of tourism and leisure activities. In particular, the use of four-wheel-drive or other vehicles in arid areas is very destructive of the vegetation and mechanically disturbs the soil structure: both effects may increase dramatically soil erosion, especially by wind. The role of the meteorologist could be to identify the periods of highest risk (high temperature and surface wind) to help regulate such activities.

The third issue results from the desertification potential of wild life. Indeed, there have been cases where wild herbivores have been held responsible for overgrazing, sometimes in conjunction with pastoralism (large flocks of ungulates in Africa, kangaroos in Australia); or elephants have been blamed for excessive deforestation, and even hippopotami thought to increase river-bank erosion significantly. Such cases pose a difficult problem: should man interfere with wild life, even in national parks and reserves? Answering such questions is well beyond the scope of this book, and it will only be mentioned here that if human intervention is felt necessary to regulate desertification processes created by wild life, a careful study of the role of meteorological and climatological factors regulating the dynamics of both vegetation and animal populations should be undertaken.

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*by M. M. Verstraete (USA)

PART II

1. INFLUENCE OF METEOROLOGICAL HAZARDS ON DESERTIFICATION PROCESSES*

Introduction

In the previous part, the role of agrometeorology in the management of resources of arid and semi-arid regions under expected climatic conditions was reviewed. It was shown (a) that agrometeorology and related sciences (hydrology, climatology, etc.) have a significant potential for improving the use and production of agro-pastoral systems in arid and semi-arid regions of the globe, and (b) that mismanagement in those sensitive regions is liable to result in severe and sometimes permanent degradation of the environment, the resources and living conditions of the populations of those areas.

In the present part, attention will focus on the role of natural hazards in the process of desertification, including their complex interactions with the management of natural resources, and on how those processes may, in turn, change the micro-meteorological and hydrological characteristics of the environment, possibly feeding back on desertification itself. It will also be seen that a deeper understanding of those mechanisms could lead to a reduction of the sensitivity of production systems to natural hazards.

Part II is structured along the following lines: a first section (1.1) deals with the interaction between drought and desertification. It is followed by section 2. "Soil erosion - land degradation - desertification", which elaborates on the interactions between fluctuating meteorological and hydrological conditions, mismanagement and the problems of soil erosion by wind and water. Then section 3 examines the role of fire as a possible factor of desertification, emphasizing how meteorological and hydrological events can influence such fires, and how such knowledge could be used to prevent extensive damages. Finally, section 4 reviews the meteorological factors controlling pests and diseases from the point of view of their possible contribution to further desertification.

1.1 Drought and desertification

This discussion should really investigate the nature of the interaction between climate variability, in general, and desertification. This is a very controversial subject, however, both because climate variability and change are the focus of an intense debate within the meteorological community, and because the question of whether man or climate is the principal cause of desertification has not been properly answered so far, even though it has been a key question for more than a decade.

For the purpose of the present discussion, desertification is understood to be a general umbrella concept to designate collectively a number of environmental degradation processes, irrespective of the presumed cause. In order to remain in the main stream of thought, almost exclusive emphasis will be given to the hot (i.e. essentially tropical and sub-tropical) arid, semi-arid and sub-humid regions.

In most countries prone to desertification, solar radiation is plentiful and temperature is not a limiting factor. By and large, plant productivity is then primarily determined by soil moisture and/or nutrient availability, hence the emphasis on the surface water balance in the context of this WMO study.

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*by M. M. Verstraete (USA)

A definition of drought will be introduced in the next section, followed by a discussion on how drought may affect desertification (and conversely) in various environments/land-use patterns. The chapter will end with a short section on drought assessment and with a guide to the existing literature on those subjects.

1.2 Drought

Drought has been the subject of numerous studies in many countries, and there is no point repeating here what is already available elsewhere. The object of this section is simply to provide a working definition of the concept of drought. The last section of this chapter should be consulted for references to some of the many works on drought.

WMO has long advocated a "supply and demand" approach to the problem of drought, a view point which is recognized explicitly in definitions such as "lack of water with respect to specific needs." A few remarks will be made here to complement this skeleton of definition:

(a) First of all, some water may be present in the environment, and yet not be accessible: for example, very few plants can really use atmospheric water vapour as such, and none can extract all the moisture present in the soil (the wilting point does not correspond to zero soil moisture);

(b) Second, a permanent lack of water is normally called aridity: drought should rather refer to a temporary shortage, even if it can be of a few years' duration;

(c) Third, drought is generally a large-scale phenomenon: the term is used at the national or regional level rather than at the field level;

(d) Fourth, it should be kept in mind that a water shortage becomes a drought only when its consequences are serious enough: not all water deficiencies are called droughts. In fact, in many countries a drought is declared only when the impact of the lack of water becomes economically significant.

In order to account for these remarks, the following definition will be used in this chapter: Drought is a temporary, harmful and widespread lack of available water with respect to specific needs.

Drought is often perceived as a lack of rainfall, but it should be made clear that the risk of drought increases when the needs for water increase, even with constant precipitation.

Without entering the debate on whether drought (and climate variability in general) or man is the primary cause of desertification, it will be made clear that, at least in some specific cases, drought and desertification may feed back on each other, thereby contributing to further degradation. For example, bad agricultural practices or overgrazing may both result in a reduction of the water infiltration rate in the soil and in a consequent increase in runoff. When this happens, less water may be stored in the soil and drought as defined above is more likely to occur. Conversely, because each plant species and/or community has a specific tolerance and response to it, drought may be an important factor in the plant population dynamics and therefore modify the carrying capacity of a rangeland, irrespective of the stocking rates actually applied.

1.3 Drought and desertification in rangelands

The problems associated with the management of rangelands have been covered extensively in Part I, , and it was shown that overgrazing and overtrampling are two serious desertification processes in arid and semi-arid grazing lands. The question addressed in this section is how drought further interacts with the management and possible desertification of rangelands.

Drought, especially when it originates from a lack of rainfall, is often accompanied by higher than usual solar radiation levels or temperatures, and it is not always clear which of the various stresses is predominant in causing mechanical damage to plant cells or plant injuries and metabolic changes. Furthermore, the impact of drought and associated conditions is dependent on the nature and state of the plant, the soil characteristics, etc. Numerous studies have investigated the impact of specific stresses on given plant species, and those should be consulted for further information.

At the space and time scale of interest here, drought interacts with desertification processes in rangelands as follows:

(a) The most direct and obvious consequence of prolonged drought is a substantial reduction of the seasonal production of the rangeland: this implies that the actual forage available is reduced and that overgrazing and overtrampling are likely to result if the stocking rate is not adjusted to the new reduced value of the carrying capacity (provided the previous stocking rate was appropriate for wetter conditions). Although the available evidence is sparse and not always conclusive, it seems that grazing lands may be able to recover from a very short period of intense overgrazing, but that their long-term average productivity is likely to be affected by persistent over-utilization;

(b) Drought also has indirect effects. It is well known that each plant species exhibits a particular resistance to water stress. Some plant species or communities are more likely to recover from a drought of given intensity and duration than others; when the rains finally come back, they are in a better position to colonize the areas left depopulated by the drought, and the dynamic population structure may be significantly changed. In particular, the carrying capacity of the rangeland may be lowered if less palatable plant species are more drought resistant than the more useful ones;

(c) Furthermore, a prolonged drought is likely to enhance the risk of soil erosion: this is an important topic that will be dealt with in section 1.6 below;

(d) A feedback between desertification and drought has been proposed by Charney and others, whereby desertification processes, by significantly increasing the surface albedo, could, for thermodynamic reasons, reduce precipitation. It should be mentioned here that this mechanism has been substantiated by numerical models of the atmosphere, but also that the available limited evidence from actual measurements in the environment contradicts this theory. This mechanism should really not be invoked until further evidence is collected and a definite explanation can be given;

(e) There is however another well-documented mechanism whereby desertification in rangelands feeds back on drought: this is that overgrazing, and especially overtrampling, tend to increase the soil's bulk density at the surface. This in turn tends to increase runoff at the expense of infiltration, and more precipitation water becomes lost to plant production. The plants surviving the overgrazing and overtrampling will have more difficulties finding the needed water, a situation which fits into the definition of drought given above.

1.4 Drought and desertification in rainfed agriculture

The contributions of agrometeorology to rainfed agriculture and the risks of desertification have been described in Part I, section 4 and in numerous publications on the subject. The focus here is on how drought interacts with desertification in rainfed agricultural systems. The case of irrigated agriculture will be treated in the next section.

The water requirements of most crops are substantially higher than those of the natural vegetation of arid regions, and rainfed agriculture can therefore be practised only in the better parts of the semi-arid areas, or in generally better-watered regions. In addition, each crop has specific requirements for soil types, temperature regimes, supplies of various minerals, etc. Clearly, a crop is always a plant species artificially introduced and maintained in a given environment: it will not give acceptable yields unless it is either adapted to this environment, or the latter is suitably modified (fertilizers, green houses, wind shields, etc.) to support the crop.

Desertification of rainfed agricultural systems usually refers to the progressive, long-term reduction in yields and productivity of the system. This may take the form of a decrease in fertility due to the slow leaching and uptake of soil nutrients, or a significant change in the water-table level, or a progressive degradation of the landscape, by gully erosion for example.

Of course, a drought does affect the yield of a given crop, and it is well known that annual harvests are well correlated with some measures of water availability, often for the past two rainy seasons. But drought per se does not modify in any significant way the potential productivity of an agricultural system. Rather, the impact is indirect.

First of all, drought will increase the risk of soil erosion by wind, a process that will be tackled in section 1.6 below. Furthermore, the risk of soil erosion by water (high-intensity rainfall events) is also greater after a long drought than after the normal dry season. Both of these processes are irreversible on the time scales of interest to the farmer and may therefore result in long-term reductions of yields. These effects may be further compounded with mismanagement practices.

It is also well known that at the border between semi-arid and arid regions, agriculturalists tend to expand their cropped acreages at the expense of what should really be grazing lands. This occurs especially during the wetter years, when the natural productivity of the rangeland seems to be high enough to support agriculture. When a prolonged drought strikes, the yields reduce drastically over the initial values and the corresponding regions may have to be finally abandoned.

When this happens, it is a disaster for both the agriculturalist and the pastoralist, because the area is not returned in a condition comparable to its original state, before it was used for agriculture: a few years of cropping may have substantially decreased the amounts of nutrients available in the soil and the abandoned areas are often prone to intense erosion by lack of vegetation cover, thereby reducing further the soil depth, its fertility and its water-holding capacity. It may take seasons or years for the natural vegetation to recolonize the region to the point when it can be used safely for grazing again and if so, probably at a lower level of exploitation, especially because all this is taking place during a period of reduced water availability.

It should be mentioned that this problem is magnified by the attempt to crop plants with too-high water needs, since droughts are then more likely to occur. It is seen again that wrong decisions in the selection of both crop type and field location may lead to both desertification and drought.

1.5 Drought and desertification in irrigated agriculture

The purpose of irrigation is precisely to control the water availability for crop or fodder production: a well-designed irrigation scheme should therefore be rather insensitive to droughts. It remains, however, that the amount of water applied to the system should be adjusted to the water being made naturally available by precipitation if the problems of waterlogging are to be avoided. The design and management of an irrigation scheme must therefore take into account the expected variability of the natural water supply.

Furthermore, the infamous salinization problems associated with the absence or malfunction of drainage systems may be enhanced by the application of additional water during drought periods.

The origin of the water is another important question to investigate: the quality and quantity of irrigation water should be sufficient to not create droughts themselves, and be insensitive to the other forms of drought that are likely to affect the cultivated areas. If the water is supplied from underground aquifers, frequent and/or prolonged droughts, together with excessive pumping, may result in the progressive exhaustion of the water resources and the ultimate abandonment of the area. Conversely, if irrigation water is brought from elsewhere, increased watering during droughts may increase the risk of raising the water table too close to the surface if the drainage system is inadequate.

It is seen that irrigated agriculture can be very productive and profitable, but that its proper management requires a good understanding of the delicate artificial conditions it creates.

1.6 Drought and soil erosion

Soil degradation through wind and water erosion is a particularly harmful desertification process because it is, for all practical purposes, irreversible (the typical time scale of soil formation is many orders of magnitude larger than the time scales characteristic of erosion processes.)

The impact of erosion on the primary productivity of a piece of land is rather complex and will be described in greater detail in section 2 below. It will be seen that soil losses due to both wind and water erosion may be estimated numerically, under specific circumstances, from the so-called Universal Soil Loss Equations (USLE). In the present section, the impact of drought on soil erosion will be qualitatively assessed from a discussion of the relevant variables of those equations.

(a) Soil erosion by wind: The USLE for wind erosion is usually written

$$E = f\ (I,\ K,\ C,\ L,\ V)$$

where E is the average annual soil loss, f is a symbol indicating that the variable on the left of the equal sign is a function of the variables shown between the parentheses that follow f, I is a soil erodibility index, K is a parameter representing soil surface roughness, C is the so-called climatic index, L is the unsheltered field width and V is the vegetation cover index.

The rationale, applicability and use of this equation will be discussed in section 2.1 below. Drought will affect directly two of those parameters: C and V. The climatic index accounts for the fact that soil erosion by wind increases as the cube of the friction wind speed and with soil moisture deficit, a situation most likely to occur during a drought.

Soil loss also increases when the vegetation cover decreases, because the latter tends to protect the soil against erosion. Since the vegetation cover is often reduced by extended droughts, increased wind erosion should be expected.

(b) Soil erosion by water: this form may also be estimated by a similar equation

$$A = f\ (R,\ K,\ L,\ S,\ C,\ P)$$

where A is the computed soil loss per unit area, f has the same meaning as in (a) above, R is the rainfall and runoff factor, K is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover and management factor and P is the support practice factor.

The use of the term "factor" here results from the fact that the function f for water erosion is usually taken to be the straight product of the variables: $f\ (R,K,L,S,C,P) = R.K.L.S.C.P.$

Again, the rationale, applicability and use of this equation will be discussed in section 2.2.

The rainfall and runoff factor is really a measure of the kinetic energy transfer from the water (individual raindrops or surface flow) to the soil particles; it is directly linked to the intensity of precipitation and the infiltration rate of water in the soil. Both of these parameters may or may not be different during droughts: only detailed site-specific studies can ascertain the impact of a drought on the water erosion through the rainfall factor. On the other hand, the vegetation cover factor C is likely to be modified by drought and this may be a major way for drought to increase water erosion. This would be particularly crucial at the end of the drought, if the first rains are very erosive.

The drought also has indirect effects through erosion. It should be remembered that the soil not only physically supports the plants but also contains the necessary water and nutrients: when the soil is eroded away, there is a net loss of those essential elements, and the fertility (productivity) of the area may be affected, especially on the poor and thin soils frequently found in arid and semi-arid regions. It is therefore seen that drought and desertification really interact with each other and may, in the long run, feed back on each other.

1.7 Drought and fire

There is evidence that fire is a major component of the plant population dynamics of certain ecosystems, and that it might contribute to desertification. This topic will be covered in detail in section 3 below, but a few remarks will be made here to underline the relation between fire and drought.

The risk of fire is dependent on the availability of fuel, a function of the previous rainy seasons in most ecosystems. Since drought tends to inhibit plant production, it will also reduce fire risks in the subsequent years. However, dead or dry vegetation burns more easily than green vegetation, even though some oily plants are particularly inflammable even when green. Therefore, the dry season is normally prone to fires and a drought will merely increase vegetation's readiness to burn. The risk of important damage is highest when a severe drought follows a period of better-than-average rainy seasons.

1.8 Drought assessment and management considerations

The first steps to be taken to reduce the dependence of a production system on drought hazard are to be aware of the risks involved and to be able to assess the start of a drought as soon as possible to allow appropriate measures to be taken in due time.

Many countries have developed what is sometimes called Drought Early Warning Systems, i.e. an information-processing system capable of integrating reports and data from various sources and of identifying the start or the likely start of a drought period. There is no space here to review the numerous systems presently in use, but the Australian Drought Watch System should be mentioned because it is fairly straightforward and does not require sophisticated computers or other equipment to be implemented. This system has been adapted and is presently operational in Botswana.

Such a system supplements but does not replace the useful and relatively easy-to-obtain statistics on precipitation distribution in space and time, and the derived data like probabilities of wet and dry spells, etc.

For practical or economic reasons, it is rarely possible to adjust the level of exploitation of a natural resource on the time scale typical of the variations of the weather. Fortunately, these resources are somewhat resilient: they can sustain short-term fluctuations without considerable damage. The mistake is of course to avoid any adjustment at all, even when the situation warrants it. If the adjustments are known to be difficult to implement or unpopular, then the level of exploitation should be set such that no long-term degradation will result from a generally constant level of utilization, even during drought times. Since the worst drought cannot be predicted and a minimum level of economic activity should be maintained, a compromise must be reached which optimizes production and minimizes permanent environmental damage. The point is that such a compromise should be attained after a careful analysis of the risks involved, and not only in terms of immediate economic benefits.

Accordingly, it is essential to collect the necessary information and, in particular, the relevant meteorological, climatological and hydrological data. The list of such useful data can be made arbitrarily long, because so many factors may be of academic interest. Economic considerations, however, usually limit the amount of data actually collected.

If a single parameter had to be selected for studying drought and its relations to desertification, it should be soil moisture. This parameter is not currently measured at a large number of locations and must often be deduced from other measurements, the most common of which are precipitation and temperature. A great deal can be accomplished already if the spatial and temporal resolution of the network is sufficient (typically, a space scale of 100 km and a time scale of a week, or less). Since evapotranspiration is also fairly difficult to measure, the next desirable parameters would probably be surface wind and some of the many possible measurements of radiation.

Furthermore, it is not clear whether additional parameters or increased time and space resolution would yield the best improvements: this will no doubt depend on the particular problem at hand. Comparatively little data are available on soil loads in the atmosphere (dust) and rivers (sediments). Conversely, existing satellite data could be used to estimate various parameters of interest, but this has not been done on a systematic basis, partly for technical reasons and partly due to the enormous amount of data available (see Part III).

1.9 Further reading on drought and desertification

Although few papers focus on the interaction between drought and desertification, many works on desertification mention the possible impact of climate variability and changes on the ecosystems and their land uses. Similarly, many papers on drought deal with the various impacts and consequences of this major environmental hazard, but without concentrating on desertification.

Very detailed and exhaustive bibliographies have been accumulated and should be consulted for in-depth analysis. Two such major data-bases must be mentioned here: the Meteorological and Geoastrophysical Abstracts, published by the American Meteorological Society, and the Arid Lands Abstracts, published by the Commonwealth Bureaux of Agriculture, in collaboration with the Office of Arid Lands Studies of the University of Arizona.

In contrast, the following few references have been selected as possible starting points for the study of the various topics covered in this chapter: it is therefore not meant to be complete, but rather to be a primer to the literature. Only recently published, preferably multi-authored works, with adequate coverage and abundant bibliographies have been selected; it is hoped that such an approach will provide a fast and easy access to the existing literature.

(a) Drought and/or desertification in general, including fire and management considerations: Glantz (1977), Hastings (1965), ICAR (1977), Johnson (1977), Mabbutt (1978), Mainguet (1979), Sheridan (1981), UN (1977).

(b) Drought: Copans (1975), Glantz (1976), Hinchey (1978), Rosenberg (1978, 1980), WMO (1975).

(c) Drought and desertification in rangelands: Howes (1978), Unesco (1979).

(d) Drought and desertification in agricultural systems, both rainfed and irrigated: Hounam (1975).

(e) Drought and soil erosion: FAO (1979), Kovda (1980).

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17. UN (1977): Desertification, its Causes and Consequences, Pergamon Press, Oxford, pp 448.

18. Unesco (1979): Tropical Grazing Land Ecosystems, United Nations Scientific and Cultural Organization, Paris, pp 655.

19. WMO (1975): Drought, World Meteorological Organization, WMO No. 403, Geneva, pp 114.

2. SOIL EROSION - LAND DEGRADATION - DESERTIFICATION*

The uncontrolled erosion of soils by wind and water will affect everyone on the face of this earth. An old proverb reads: "Man strides over the earth, and deserts follow in his footsteps." Now that man has covered the earth, he must learn to protect the land where he is standing. The challenge is great; but the consequence of failure is potential mass starvation of millions of people and animals (UNEP).

The geomorphology of the earth illustrates that erosion is a continuing process. The "contribution" of man has been to accelerate the process. Erosion modifies the soil surface and influences soil productivity. The extent of the change can be so small as to be almost insignificant. But one can study the geomorphology of an area and then realize that changes have occurred and will continue to occur. Man's activities tend to accelerate the rate of change; and he becomes concerned when the changes are so rapid and drastic that land degradation and accelerated desertification make further use of the soil and water resources impossible without extensive capital outlays. The longer the planning horizon of the farmer, the greater the value of soil conservation (Taylor *et al*., 1979). Changes in climatic patterns may also accelerate the desertification process so that a once-productive area will no longer produce satisfactory crop yields. While significant climatic changes do occur, the major cause of desertification is usually the mismanagement of the soil and water resources.

The production of agricultural crops in a semi-arid or arid area does involve risk beyond the control of mankind. If these areas are to continue to be utilized for crop production, we must identify the role of erosion and its impact on soil productivity and desertification.

The effect of wind and water erosion on soils is quite different, but both involve the movement of soil. The movement may be a few millimetres or thousands of kilometres. The following discussion will be limited to erosion effects in semi-arid regions and may not describe these erosion processes in more humid regions.

2.1 Wind erosion

Wind erosion involves a sorting or "fanning" of the coarse and fine material on the soil surface. While wind erosion may start in one area of a large field, eventually, the entire field will become eroded. The fines may become airborne and carried out of the field. The coarser material will shift around in the field and may cause normally protected areas to blow. Whenever non-erodible areas are encountered, the shifting material will deposit, thus increasing management problems. As the fines are removed from the soil surface, a portion can be replaced by increasing the depth of tillage, but this is a temporary measure and may result in increased erodibility as the fines are again removed from the surface soil. The loss of fine material due to wind erosion represents a loss of soil nutrients and water-holding capacity that will further reduce crop yields. As yields decrease, less organic matter is returned to the soil; and therefore wind erosion may increase unless it is controlled by tillage, wind barriers, or crop stripping. In any case, the net result is soil degradation and increased desertification. If the erosion is less than the tolerable soil loss, the soil regeneration process will maintain soil productivity.

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2.2 Water erosion

Water erosion is characterized as sheet, rill or gully erosion. Except for extremely large particles, water has sufficient energy to erode the entire soil profile. In the areas receiving intense convective thunderstorms most erosion results in small rills or gullies. In the case of rills, the farmer may work over them; and with a few farming operations, the evidence of the previous rill erosion may be obliterated. However, this does not mean that the loss in soil productivity has been corrected. Unless some method of land forming is used, the rills will continue to form, and may increase in size with each storm. As the eroded material is transported down the slope, the coarser fractions will settle out as the velocity of the water decreases. Deposition will continue in stream or river channels, or when the rivers empty into large bodies of water.

2.2.1 Soil renewal

The soil formation process is very slow, and even under the best natural condition it may take 30 years to develop 2.5 cm of organic-matter-enriched topsoil (Hall, et al., 1981). For semi-arid regions the time is much longer. Several cm (10 to 25) of topsoil plus an adequate subsoil are needed for the production of most field crops. The development of a complete soil profile would require hundreds of years even with zero erosion (which is never the case). While erosion from most soil is much higher with cultivated agriculture, we know that geological erosion has always been present. The erosion level that would allow continued cultivation without a decline in productivity is considered the soil loss tolerance (T) value. In a temperate climate, soil renewal rates of 1.1 ton/ha/yr is considered average when the subsoil is formed from soft materials. When the soil formation is from rock, the soil formation rate is much slower (Smith and Stamey, 1965). For the coarse textured soils of the semi-arid regions, the soil formation can be assumed negligible.

Most people do not have a concept of airborne dust concentrations and soil erosion. Chepil (1960) described some erosion relationships (Table 14). It is apparent from Chepil's descriptions that erosion losses of even 20 ton/acre/yr would not be easily detectable and would far exceed soil renewal.

The importance of topsoil was described by Dr Bill Harris in his comment "Topsoil is that material which separates us from starvation."† It's not a question of whether we need to control erosion, but rather how much productivity we have already lost. The cost may be high, but the consequence of failure is mass starvation.

2.2.2 Controlling erosion

For man to utilize the soil, water, and plant resources of semi-arid and arid regions, erosion must be controlled. If the area is used for grazing, then a good cover of grass, shrubs, and trees must be maintained to protect the soil surface. If the area is cultivated, then surface residues, land-forming to reduce runoff, or tillage must be used to maintain a soil with good infiltration, a high water-holding capacity, and resistance to erosion. Unless measures are used to control erosion, the productive life of a soil will become limited.

†Personal communication

Table 14 - Relationships among quantity of wind erosion, effects of erosion, and relative field erodibility

Quantity of erosion	Description of erosion	Annual soil loss*	Relative field erodibility
		ton/ha/yr	
None to insignificant	No distinct visible effects of soil movement	Less than 11	Less than 0.25
Slight	Soil movement not sufficient to kill winter wheat in boot stage	11 to 110	0.25 to 1.0
Moderate	Removal and associated accumulations to about 2.5 cm depth sufficient to kill wheat in boot stage	110 to 367	1.0 to 5
High	About 2.5 to 5 cm removal and associated accumulations	367 to 733	5 to 20
Very high	5 to 7 cm removal with small dune formations	733 to 1100	20 to 150
Exceedingly high	More than 7 cm removal with appreciable piling into drifts or dunes	More than 1100	More than 150

*Occurring in the vicinity of Garden City, Kansas during 1954 to 1956.

Undesirable soil characteristics resulting from erosion include loss of natural fertility and water-holding capacity, reduced infiltration, and a decrease in soil depth. The impact of the soil loss will depend on the original soil characteristics, and soil depth. But in any case, high levels of productivity under conditions of erosion will require increased energy use and more intensive management.

Some basic techniques for minimizing wind erosion hazard include covering the soil surface with crop residues; roughening the soil surface with soil ridges and clods; installing strips of erosion-resistant crop or tree barriers; stripping the soil surface with alternate high residue and low residue or fallow strips; or reducing wind force on the soil with shrubs, taller plants, or trees. The most effective and desirable method will depend on the unique conditions of a particular site. While each method has certain advantages, none can guarantee complete protection during extended drought periods.

The end result of land degradation and desertification is a reduction in the capacity of the soil, in its natural environment, to continue producing specific crops under a specified management system. The concern about the reduced production capacity was lessened as the usage of commercial fertilizers become common practice. While some of the various nutrients can be replaced "from a sack", some essential soil components cannot be quickly replaced. For example, the soil fines (the silt and clay fractions) are readily eroded by wind and water erosion but cannot be replaced except by bringing them up from the subsoil. For some soils there are no fines in the subsoil. Soil organic matter can be replaced; but the process is slow, particularly in arid and semi-arid regions. As the surface soil erodes, exposing more subsoil, the degrading soil structure "increases the susceptibility to erosion, surface sealing, and crusting and leads to poorer seedbeds" (USDA). In rare cases erosion of the topsoil may expose a buried soil and will not result in reduced productivity.

As the erosion process continues, it tends to accelerate the rate of land degradation. This results in an increase in cost of control measures. Simply stated, "Don't wait until land degradation starts reducing crop yields to begin soil conservation measures".

Agrometeorological data from an area are essential to the development of management systems or the selection of control measures. Data on wind speeds, wind direction, rainfall and evaporation are needed to estimate wind erosion using the equation $E = f(I'K'C'L'V)$,

where E = Estimated annual soil erosion,

I' = Soil erodibility index,

K' = Soil ridge roughness factor,

C' = Climatic factor,

L' = Field length along prevailing wind direction, and

V = Equivalent quantity of vegetative cover.

The erodibility of the soil I' can be estimated from soil-type data, K' is primarily influenced by tillage practice, and V can be estimated from crop production figures. The C' term utilizes historical meteorological data of average wind velocity, monthly rainfall, and evaporation. The L' term will vary depending on wind direction unless the unprotected field length is large (say 1 000 m).

Water erosion losses are estimated from the USLE equation: $A = RKLSCP$,

where A = Soil loss in mass/unit area,

R = Rainfall and runoff erosivity,

K = Soil erodibility factor,

LS = Topographic factor for slope length and steepness, and

CP = Cropping-management-supporting practice factor. Rainfall amount and intensity must be obtained from meteorological data.

The values for the terms K, LS, and CP can be determined from agronomic data on the crops, and engineering data on the soils.

Thus, when soil erosion exceeds soil renewal, land degradation and desertification begin. The problem is critical in arid and semi-arid regions because significant soil renewal is measured in hundreds of years. The approaches to proper utilization of soil and water resources in these regions would include estimates of the soil erosion rate using existing erosion models, then planning cropping and tillage practices that will control erosion.

2.3 Agrometeorological aspects of land stabilization*

As mentioned above, one effective method for stabilizing soil surfaces affected by wind or water erosion is to plant (or sow) trees, shrubs or types of grass which have fast-growing and well-developed root systems. This practice is known as land stabilization. Land renewal is done on a wide scale in the deserts, semi-deserts and even mountainous regions of the Soviet Union.

During the last few years, a number of African countries have been doing a considerable amount of work to create a "green belt" along the southern edge of the Sahara. An extremely large number of papers have been written on the renewal of the ensemble of desert plant communities and on the agro-technical, biological and agronomic aspects of this problem.

The present section covers the environmental impact of land renewal on pastureland and the agrometeorological aspects of this work in desert and semi-desert pastureland.

The creation of artificial plant communities over large areas, which is associated with the destruction of poor vegetative cover and the change of soil state considerably modifies the climate of the atmospheric surface layer and soil.

The climate of the atmospheric surface layer and soil, vegetative cover and animal world represent a very dynamic natural complex. Variability of microclimatic conditions causes not only spatial differences in the rate of development of plants, their growth and yield formation but also is one of the main factors of non-homogeneity of vegetation and soil cover. In turn, the structure of each plant community and even its individual components significantly affect the formation of the environment microclimate.

Studies of the microclimate peculiarities help to properly use the regularities of spatial distribution of climatic elements, to specify heat and water requirements of plants and finally to solve practical problems concerning phytomelioration of pastures (An, Gringof, Konovalova, 1978).

We shall consider below several examples showing the difference between meteorological parameters of natural and artificial desert communities and landscapes.

During the formation of tree and shrub stands the peculiarities of microclimatic conditions are, to a great extent, associated with the conditions of radiation transmission by crowns of desert vegetation.

Observations made in regions of Central Asia (USSR) with different landscapes allowed one to determine specific features of radiation and heat balances in vegetation stands.

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According to Aizenshtat's data (1958), in the daytime the upper half of the crown of Haloxylon aphylum receives 4-5 times more heat than its lower half. At night the loss of heat by radiation by the upper half of the crown exceeds that by the lower half by a factor of 3-3.5. Gunin and Dedkov found that in eastern Karakum in summer the amount of total solar radiation varied from 152 cal/cm^2 per day under the crown to 650 cal/cm^2 per day above the crown and that of diffuse radiation varied from 38 cal/cm^2 per day under the crown to 176 cal/cm^2 per day in the intercrown space. The radiation balance was 109, 92 and 266 cal/cm^2 per day in the crown, under the crown and in the intercrown space, respectively.

According to the same authors, the stress of the radiation regime elements decreases in the direction from the periphery of the crown to the stem. Radiation balance values under the saxaul crown at the periphery parts and near the stem are 1.6 and 4 times lower, respectively, than in the intercrown space. At night the difference is less pronounced. Total radiation under the crown at the periphery parts and near the stem is 1.9 and 3-5 times lower, respectively, than in the intercrown space. Diffuse radiation under the crown is 10 times lower than in the intercrown space. At midday the periphery parts of the crown intercept 68% of direct solar radiation and those near the stem 83-90%.

Saxaul aphylum has the greatest effect upon the transformation of solar radiation. It intercepts up to 40-83% of total radiation coming to the upper boundary of the crown. On sandy soils crowns of Haloxylon persicum and Ephedra strobilacea intercept 56-60% and 70% of total radiation, respectively. Individual plants growing in central Karakum intercept from 50% to 95% of direct solar radiation.

According to Nurberdiev's and Mukhomedova's data (1972), maximum shading of soil by Calligonum sp. is observed in May. And beginning with the falling of sprigs it sharply decreases. Small, medium and large shrubs of Calligonum sp. intercept 50-57%, 70-74% and about 80% of direct radiation, respectively.

Unequal irradiation of soil by sunbeams under crowns results in the difference in temperature and moisture of soil and air. In the daytime, soil surface temperature under the crown periphery and around the stem is lower by 9°-13°C and 30°C, respectively, than in the intercrown space. At night, soil surface temperature under the crown is lower than in the intercrown space by 0.1°-4°C.

Soil temperature under plants is lower than in open spaces (Table 15).

Table 15 - Difference between mean daily temperature in soil and air in saxaul stands and in the open space. Central Karakum, spring-summer of 1975-1976

Difference between temperature in soil and in open space in °C at various depths in cm					Difference between temperature in inter-plant space and in open space in °C at various heights in cm		
0	5	10	15	20	10	50	200
-4.0	-2.4	-2.1	-2.7	-1.7	-0.3	+0.7	-0.1

The daily soil surface temperature range in stands is lower than in the intercrown space by 25°-30°C.

Air temperatures in stands are also, on the average, a little lower than in the open space. However, sometimes they can be higher because of weakened wind velocity and turbulent mixing in the surface layer of the atmosphere.

Artykov's observations (1975) show that at night and in the morning, air temperatures in stands are lower than in the open space by 2.0° to 2.5°C. At midday, air temperatures in stands exceed those of the open space by 0.5°-1.5°C. And in the evening they become equal.

Forest stands noticeably affect wind velocity. Thus, for example, if at an altitude of 2 m in the open space, wind velocity attains 9-10 m/sec, in saxaul stands it decreases to 5-6 m/sec and in an orchard of fruit trees it falls to 2-3 m/sec. In central Karakum when in the open space wind velocity is small, in saxaul stands it decreases by a factor of 2, 2-5 and 2-8 at altitudes of 2, 0.5 and 0.1 m, respectively.

In the daytime, relative air humidity under crowns differs slightly from that of the intercrown space. In individual cases under saxaul crowns it can be higher by 2-3%. At night, relative humidity of air in the intercrown space is usually higher than under crowns. The difference can reach 21% (Gunin and Dedkov, 1978).

Tree and shrub stands considerably influence the redistribution of precipitation. Depending on the plants' structure and stage of development, they intercept from 10% to 55% of precipitation. The falling of precipitation down stems constitutes from 1 to 25%.

Calculations made by Gunin and Dedkov (1978) reveal that in stands of Aristida karelini, Ammodendron conollyi and Calligonum sp. sp. for an area taken as a whole no more than 2.2% of precipitation is intercepted by plant crowns and 0.2% falls down stems and branches. Crowns of Haloxylon persicum intercept from 2.3 to 4.1% of precipitation, 0.6-1.2% falling down stems. Crowns of Haloxylon aphyllum intercept 11-12% of precipitation, 5-6% falling down stems.

Wind plays an important role in the redistribution of precipitation. Upwind sides of stands intercept more precipitation.

Redistribution of precipitation by crowns has an effect upon the formation of moisture supplies in soil. We shall describe a profile of moisture distribution in soil under a shrub of Haloxylon persicum 3.5 m high after fall of 16.5 mm of precipitation in February 1966 with north wind (from Artykov's data). Soil at the northern upwind side proves to be more moistened than at the downwind side. Around the stem, due to the flowing of precipitation down it, soil layers down to 50 cm are moistened to the least field capacity (LFC) and higher (up to 10-12%). Within a radius of 50 cm from the stem there is a "rain shadow" where soil remains dry and its moisture is close to the wilting point (about 2%). The effect of a saxaul shrub upon the redistribution of precipitation is observed within a radius of 2.5 m from the shrub. And the depth to which soil is moistened at the upwind side is greater than at the downwind side.

The above features of the hydrometeorological regime under stand crowns certainly affect the formation of peculiar plant communities. This was often noted by geobotanists (Nechaeva, 1958; and others).

The creation of artificial ecosystems requires some improvement of moisture and physical properties of soil and its additional moistening. This is achieved by a system of agrotechnical measures and, in particular, by making moisture- and sand-accumulating furrows.

Experiments conducted at the Kyzylkum desert station of the Institute of Botany (of the Uzbekistan Academy of Sciences) show that in spring, the soil gets wet due to precipitation runoff down to 120-130 cm on grey-brown soils of gypsum deserts while on wild lands, it gets wet only down to 40-60 cm. On soils with unfavourable moisture and physical properties, furrows which accumulate sand are made since sand absorbs precipitation moisture very well.

However, the microclimate of deserts is substantially changed only under the influence of those reclamation measures which radically change the water balance of a territory. This means the use of groundwater supplies constituting large reserves which enable the guaranteed growing of forage crops for additional feeding of sheep in winter.

Moistening of the root zone under irrigation leads to a sharp redistribution of heat coming from the sun.

According to Orlovsky and Utina (1977), the change of the heat balance components caused by irrigation shows that in deserts in the daytime, radiation balance is spent upon turbulent exchange of heat with the atmosphere (80%) and upon the flux of heat into soil (20%). Under irrigation in the daytime, radiation balance increases by more than 40% and is spent upon evaporation. Under those conditions the heat flux into soil (15% of the radiation balance) is compensated by the heat flux from the atmosphere to the less heated underlying surface.

Change in water, radiation and heat balances under irrigation results in the formation of peculiar climatic and microclimatic conditions.

In irrigated oases there never occurs extremely hot and dry weather with air temperatures exceeding 37.5°C and relative humidity equal to 0-20%. Here the sum of air temperatures for a growing season is lower than in deserts approximately by 300°-400°C.

Already in May, differences in mean monthly air temperatures and absolute humidity amount to 1.7°C and 2-3 hPa respectively. In July-August the differences are maximum and equal to 3.0-3.3°C and 5-6 hPa respectively.

The effect of irrigation upon the diurnal course of meteorological elements is more pronounced. In the daytime, air temperatures in oases are lower than in deserts by 2°-4°C. In periods with extremely hot weather the difference attains 10°-15°C. As for relative humidity, the greatest difference (25-30%) between irrigated oases and deserts is observed in the evening; in the daytime it smoothes away.

Thus, irrigation by ground and surface water produces a greater effect upon the hydrometeorological regime of the land reclaimed than phytomelioration. But this does not diminish the importance of the latter.

Tree and shrub stands play an important role in deserts. As stated above, they reduce wind velocity, retain snow, decrease wind erosion of soil, enhance the efficiency of solar radiation and improve the microclimate.

Under crowns of trees and shrubs in stands new plant communities are formed. They are composed of cereal grasses of early spring development cycle and plants of Chenopodiacea. Pasture vegetation productivity increases. Dried grasses are preserved. Moreover, tree and shrub stands serve as a shelter for sheep both in summer and in winter.

2.3.1 Agrometeorological support for pastureland renewal

One of the progressive directions in arid land reclamation for plant growing is phytomelioration of pastures with poor associations of plants. The characteristic feature of this work is that it is based upon scientific recommendations on the creation of artificial phytocoenoses producing high and stable yields of vegetative matter and establishing favourable conditions for growing various life forms of desert plants.

It is well known that as a result of phytomelioration, yields of vegetative matter from pasture plants increase, on the average, 2-3 times. Rise in the production function of vegetation leads to increase of the transformation function of vegetative cover consisting in regular changes of geophysical and geochemical regimes of biogeocoenoses.

Creation of artificial phytocoenoses over large areas which is associated with the destruction of poor vegetative cover and the change of soil state considerably modifies the climate of the atmospheric surface layer and soil. During the formation of tree and shrub stands the peculiarities of microclimatic conditions are, to a great extent, associated with the conditions of radiation transmission by crowns of desert vegetation.

Unequal irradiation of soil by sunbeams under crowns results in the difference in temperature and moisture of soil and air.

It is, however, known that at present the efficiency of phytomelioration is not high enough because the sowing of phytomelioration plants does not always give desirable results.

Specialized agrometeorological assessment of desert areas is one of the necessary conditions for successful organization and efficiency increase of phytomelioration measures.

Success of phytomelioration depends on a number of factors, primarily, on moisture conditions of the territory.

In accordance with an ecological interpretation of the index of moisture conditions (IMC)*, the territory of Central Asia is divided into four main agroclimatic zones with: IMC = 0.40 (bad moisture conditions), IMC from 0.40 to 0.59 (medium conditions), IMC from 0.60 to 0.79 (moisture conditions better than medium) and IMC from 0.80 to 1.00 (good moisture conditions).

Since during phytomelioration of pastures and forests moisture conditions in spring are of crucial importance for both emergence, acceleration and growth of plants, the proposed scheme for regionalization can be well used for the assessment of conditions for phytomelioration.

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*See Part I, section 1.2 of the present report.

In the first zone bounded by IMC <0.40 the conditions for phytomelioration are essentially unfavourable. However, the zone delineated by the isoline of IMC = 0.30 is divided into two sub-zones. The upper sub-zone has bad conditions. The other sub-zone with IMC equal to 0.30-0.40 may be regarded as having satisfactory conditions for phytomelioration in years with enhanced amount of precipitation.

It is established that precipitation over 100 mm during the period of December to April creates comparatively good conditions for the yield of ephemer grasses. The probability of such amounts of precipitation may be presented as follows:

Zone	Sub-zone	Number of years out of 10 with precipitation over 100 mm in the period of December-April
I	a	1
I	b	2-3
II	-	4
III	-	5-6
IV	-	7-8

Thus, in Sub-zone Ib, phytomelioration may be successful, on the average, in 2-3 years out of 10.

The assessment of agroclimatic zones according to the extent of their favourability for phytomelioration is given in Table 16. Turkmenistan is taken as an example. It is seen that only a very small part (6%) of the territory has comparatively favourable conditions for phytomelioration. And most part of it is in very dry (43%), dry (35%) and moderately arid (16%) zones.

The practice of phytomelioration also requires a differential approach to the assessment of agrometeorological conditions according to landscape types and relief elements. For this purpose in the Karakum, in areas adjacent to Kopetdag there were distinguished five geomorphological microregions according to the extent of favourability of conditions for the rooting of sown plant.

1. The zone of contact of Takyr Soils and Takyr Depressions with sandy soils

In this zone, moisture conditions are most favourable. Satisfactory rooting of plants is provided with precipitation of 35-39 mm in the pre-sowing period, available moisture supplies of 30-49 mm in the 1 m soil layer or the depth to which soil is wetted equal to 25-39 cm. The frequency of favourable years for the rooting of plants constitutes 8 years out of 10.

2. Takyr Depressions

The frequency of good and satisfactory years for rooting is 3 and 4 out of 10, respectively.

3. Small hummocky sands and lower parts of sandy ridges

They occupy the largest area. Good and satisfactory rooting is observed in 3 and 4 years out of 10, respectively.

4. The middle part of east and west slopes of sandy ridges

These are the most unfavourable sites for phytomelioration. The frequency of favourable years for rooting is three out of ten.

5. Tops of Sandy Ridges

Moving sands (barchans) require to be fixed. Favourable conditions for the rooting of phytomelioration plants are observed in four out of ten years.

The assessment of the territory from the standpoint of favourability of conditions for phytomelioration is required to reconsider some conventional views in the field of desert phytomelioration, to impose new demands on the arrangement of works aimed at improving pastures and to pose a number of problems for agrometeorological support of range and pasture management.

Thus, for example, in very wet years phytomelioration plants may be sown in 90-100% of pasture areas; in wet years they are not sown on east and west slopes of sandy ridges; in years with medium moisture conditions it is advisable to sow plants in zones of contact of takyr soils with sands, in takyr depressions here and there covered with thin layers of sand and in lower parts of small hummocky sands. In arid years plants may be sown only in the zone of contact of takyr depressions with sands.

Optimum areas under phytomelioration plants may be predicted every year on the basis of the criteria developed.

Actually, in years with good, medium and insufficient moisture conditions it is advisable to sow 90%, 40% and 5% of pasture areas, respectively.

Table 16 - Agroclimatic assessment of Turkmenistan for phytomelioration

Agroclimatic zones and IMC	Area occupied (%)	Extent of favourability of natural conditions for phytomelioration
Very dry (I), IMC of 0.20-0.39	43	Very unfavourable. Phytomelioration is advisable on sands in oases and on the banks of canals
Dry (II), IMC of 0.40-0.59	35	Unfavourable. Not very satisfactory on sands around wells. Good on sands in oases and in locations with artificial collection of rain water
Moderately dry (III), IMC of 0.60-0.79	16	Satisfactory on sands around wells. Good on dams and firths of Karakum canal and in locations with artificial collection of rain water
Moderately wet (IV), IMC of 0.80-1.00	6	Good on sands around wells. Satisfactory and good on ephemer turf ploughed up

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3. FIRE AND DESERTIFICATION*

3.1 Assessment of agrometeorological factors in fire risk

Introduction

Fire and man have to live together in an environment with a finely balanced relationship. In Australia the effects of fire are evident in almost all the major vegetation types. The Australian flora has apparently adapted to fires and to available fire regimes; the adaptation of individual plant species may be attributed either to a behavioural response to a certain fire regime, or it may be expressed as a resistance to fire itself.

The history of fires from geological times to the present is a valuable reference when considering desertification. The general subject is well covered by a publication edited by Gill, Groves and Noble (1981) and extensive reference has been made to that text. Although fire can have beneficial effects on some vegetation, it can also destroy human life, homes, crops, cattle and hence the means of making a living.

Some ecologists and conservation scientists argue that the natural build-up of fuel should be allowed to proceed until a fire occurs. Fire authorities and forest managers use prescribed burns to minimize the danger of a major conflagration. Fires affect the quality of water in catchment areas and the needs of the community have to be guarded. In any case feral animals such as pigs, goats and rabbits as well as domestic grazing animals and introduced plants have already altered almost all natural ecosystems to a varying degree.

Fire history and desertification

The frequency and intensity of fire is inextricably related to climate. The moisture regime dictates the quantity and condition of potential fuel supplied by natural vegetation which in turn regulates the fire regime.

During the Eocene period, theory has it that Australia was in close proximity to the Antarctic Continent which had little ice at the time and the waters surrounding Australia were relatively warm. As a result there was an attendant high level of precipitation. The evidence that exists suggests that the predominant vegetation over most of southern Australia south of Alice Springs was rain forest; this evidence has been obtained from both pollen and fossil data (Kemp, 1981). Although paleo-botanical evidence suggests closed forests growing under conditions of high and probably evenly distributed rainfall there is no concrete evidence of forest fires at that time. It seems unlikely that fires were common but with moist air, thunderstorms probably were frequent inland, and lightning could have been an ignition source. Such fires that may have occurred would have been of considerable intensity because of the abundant fuel that would have accumulated beneath the trees.

At the end of the Eocene period the climate took on a new character; a cooling trend was started that led to the formation of the ice cap on Antarctica in the Miocene period and to glaciations in the northern hemisphere at a later date. The rapid increase of ice around Antarctica led to atmospheric circulation patterns not unlike the present regime.

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It must be concluded that the present-day aridity of Central Australian regions was due to a change of climate and not to destruction by fire. According to Kemp (*ibid*) grasslands developed under conditions of at least periodic aridity; the modern sclerophyll forest which covers most of Australia is relatively fire-prone and probably had its origin between the latest Miocene and the early Pleistocene.

Although the degradation from rain forest to open sclerophyll vegetation in inland areas most probably is the direct result of climatic change, it is possible that natural lightning-generated fires could have accelerated the trend towards dry open woodlands. During the time span when arid phases became more common as the climate varied a higher frequency of fires would have favoured the spread of sclerophyllous woodland at the expense of the more fire-sensitive areas of rain forest due to the inherent build-up of litter on forest floors. Even a fire occurring naturally every few hundred years, or within the life span of the eucalypts, would have been sufficient to favour the drier, more open vegetation (Kemp, *ibid*). The more frequently fires occur then the more favourable the conditions are for the generation of fire-prone vegetation. According to Kemp (*ibid*) it is merely conjectural whether such a mechanism operated during the Tertiary period as there is no concrete argument to support this theory; all that can be said is that the frequency of fire necessary to initiate such a trend is well within the scope of naturally occurring fires. Besides lightning, other natural sources of ignition could have been burning coal seams, resulting from spontaneous combustion, or volcanic eruptions. Volcanoes were active along Australia's eastern and south-eastern coastal fringes from Palaeocene to Holocene times.

The sclerophyll species which constitute an overwhelming majority of the Australian flora at present are not only considered fire-tolerant but are sometimes classed as fire-requirers and fire-promoters (Jackson, 1978). It has even been suggested that the sclerophylls have acquired by selection the capacity to tolerate and use high fire frequencies in competitive balance with other communities and in the process they have become adapted to soils of low fertility. (Jackson, *ibid*).

Occupation of the continent by man brought skills which resulted in man-made fires. It is thought that the subsequent increase in fires resulting from the impact of man would lead to more open vegetation and a floristic change from fire-sensitive to fire-adapted vegetation.

Prior to the occupation of Australia by aborigines the fire-sensitive *Casuarina* vegetation and associated cool temperate growth predominated. Following aborigine occupation, partly due to changing climate and partly due to fire, open woodlands or forest of *Eucalyptus* and myrtaceous shrubs developed with an understorey of grasses.

The maximum firing of forests does not appear to have occurred until the arrival of Europeans; charcoal deposits at this time rise to more than three and a half times the value of the highest rise seen during the aborigine period and more than sixteen times the highest level during the period when only natural fires occurred. It may well be that Europeans, unlike the aborigines, probably allowed greater accumulation of forest debris to occur so that fires would have burned more intensely than before.

The response of forest vegetation to fires

Gill (1981) has pointed out traits which enhance survival of plants and also traits associated with enhanced reproduction. Above-ground fires may entirely destroy some vegetation, however other vegetation survives because buds are protected by soil.

The underground cover is a valuable refuge for living matter during a fire. Soil is an effective insulator and high soil temperatures would be expected to be confined to a shallow depth. Packham (1970) estimates that only about five per cent of the fire's heat penetrates the soil.

As Gill (loc.cit) points out plants have a mechanism for placing buds in subterranean positions. Both root buds and lignotubers serve to assist certain vegetation to survive fires. As would be expected aged plants seem less able to survive fires than the younger mature plant. Vitality can be reduced by repeated burning and Grano (1970) found for the south-east of USA that biennial burning eliminated sprouting on 59 per cent of rootstocks and annual burning eliminated sprouting on 85 per cent of vegetation.

Sprouting may be considered as a process of adaptation by the plants to stress, and fire certainly does apply the required stress.

Gill (1981) has given the following findings regarding plant resistance to fire:

- Plant traits considered adaptive to fire may be distinguished by their vegetative survival; enhanced reproduction through fire-stimulated flowering; enhanced reproduction through on-plant seed storage and fire-stimulated dispersal; enhanced reproduction facilitated by in-soil storage with fire-stimulated germination;
- A single trait such as vegetative survival and resprouting or hardseededness, may be adaptive not only to fires but also to other variables;
- Different species in the same environment may have different adaptive traits but persist with equal success;
- The significance of a trait and its adaptive value can only be considered within the context of the life cycle;
- For fire as an environmental variable, adaptation must be considered in terms of the fire regime type (i.e. peat or above-ground fire), season, frequency and intensity of fires;
- Fire is only one of a set of selective agents faced by a plant population: those traits which enable survival and reproduction during a succession of fires must also enable survival and reproduction to take place during the stresses imposed by other selective agents, such as drought;
- Species' responses to fire regimes may be many and varied but by defining fire intensity biologically (100 per cent crown scorch) and by using responses of mature plants, these responses may be classified.

Fire in tall open forests

At maturity the giant eucalypt forests of Australia may reach heights of 50 to 110 m although tree densities may be as low as 20 to 40 per hectare and the cover of the tree canopy only 35 to 55 per cent. Fires may burn through the upper canopy, the undergrowth and litter, or on peat and soil-humus layers. These have been designated 'crown', 'surface' and 'humus' fires. Wet sclerophyll forests need an annual rainfall of 1 500 to 2 000 mm with the driest month above 500 mm. In general the higher the rainfall the greater the total amount of fuel produced and of course the wetter the season the less the expected fire frequency. The fertility of soils is likely to be depleted in high rainfall areas subjected to repeated severe burning. Poor soils in turn tend to support markedly sclerophyllous undergrowth (Ashton, 1981) which is low in mineral matter and hence highly flammable. Ridges and spurs exposed to dry winds will tend to carry fire more easily and constitute 'fire paths'. Fires will tend to burn severely on the windward slopes in contrast to fires on the lee slopes. In eucalypt forests the deciduous bark streamers, rough fibrous bark or lichen epiphytes tend to carry fire up to the canopy under certain conditions, thence to disseminate the fire ahead of the main fire front; this phenomenon is known as 'spotting' or spot firing. Crown fires are dependent on a sustained wind for maintenance; they do not persist when an unfavourable downhill slope is encountered. Fire whirlwinds are generated under suitable conditions with high intensity fires. During such intense conflagrations whole trees are often bodily hurled tens of metres.

Shea, Peet and Chaney (1981) describe fire whirlwinds as follows: Fire whirlwinds are associated with strong convection from fires; they usually occur on the lee of slopes near ridge tops and can occur when the surface winds are strong. The occurrence of fire whirlwinds may depend on air stability, the vertical wind structure and the fire pattern in relation to topography and the prevailing wind direction. The intensity of the whirlwinds depends on the rate of energy release and hence controlled fire ignition can restrict their occurrence in trial burns. The base of the whirlwind can break away from the point of initiation and move downwind showering its track with spot fires. People have been killed when whirlwinds have moved out of the fire and overrun fire crews or trapped them by mass spotting into unburnt fuel. In the past fire-fighting crews have been trapped on a lee slope either by an unexpected wind change or because the prevailing wind direction was not recognized and they were working down-hill into an upslope thermal wind which was blowing in an opposite direction to the wind aloft.

The potentially high flammability of the forest may in fact be the secret of the success of forest regeneration under favourable conditions. Such a philosophy was expressed by Mutch (1970) for the USA. The protection offered by various tissues is chiefly related to the delay of heat penetration to vital areas. Ashton (1981) suggests that the flammability of the crowns in a eucalypt forest may be expected to create conditions of explosive heat for a very short time. It is possible that the protection offered by seed capsules could be sufficient to protect the seed for this critically short period and if this is the real explanation then the timing is perfect. The harvesting of the seeds of the forest is largely carried out by insects. In eucalypt seed is stored in the canopy of the tree where capsules persist for two to three years ensuring that at least the crop of one good flowering season is available; after a peak flowering year, the storage of seed in this fashion may amount to fourteen million seeds per hectare. Mount (1969) suggested that due to the peculiar phenology of many of the eucalypts, the moist capsules are situated below the current foliage and heat would therefore tend to be swept upwards and away. It has been observed that during the passage of the front of the crown fire, before the arrival of the surface fire, a cool updraught of air occurs; these occurrences could be critical for the survival of seed in capsules.

Responses of forests to fires

Fire plays a role in determining the make-up of a forest. In south-eastern Australia recurring fires of high intensity have reduced the distribution of wet sclerophyll species and encouraged dense scrub and coppice forest regeneration in once park-like forest and woodland communities (Pryor, 1939). There is evidence that repeated and frequent burning may convert open forest with a shrub understorey into open forest with a grass understorey.

Dry sclerophyll forests exist in a Mediterranean-type climate with a summer drought, high temperatures and periods of hot dry winds. Although such forests are very fire prone and highly flammable, they are fire tolerant and capable of surviving intense fires and recovering rapidly thereafter. After a fire, regeneration can take place by vegetative regrowth, or from seed residue in the soil or seed released from plants. The introduction of exotic grasses into the forest may result in higher fire frequencies. Regular recurrence of fire may cause changes in the density of shrubs in the understorey. According to Gill (1975) a situation could arise where a zone which had rain forest potential could be maintained at a eucalypt stage of succession by frequent fire. A change in forest microclimate is one of the most important indirect effects after fire. Fire removes the litter and the lower strata of vegetation which could limit infiltration of rainfall and solar radiation. The bird and animal population is also affected by fire. Plants suffering suppression from competitive vegetation or pests and disease may be stimulated as a result of fire, not only by the thermal effect but by a change in the microclimate. Plant nutrients are recycled and the combination of exposed forest soil, the removal of dead material and its conversion to nutrient ash, promotes plant growth. Although nitrogen is lost during a fire, an improvement in its availability following a fire often compensates for the loss in the short term. The balance between nitrogen loss and improved availability depends on such things as soil type, soil pH changes, the amount of ash produced and the temperature to which the soil is heated. It is believed that in the long term nitrogen lost during fires is returned to the ecosystem primarily through fixation of atmospheric nitrogen by the root-nodule bacteria of certain understorey shrubs such as the native legumes.

Legume thickets do not result from low-intensity fires. The most extensive thickets of legumes develop on favourable sites following large, high-intensity wildfires (Peet, 1971). The phosphorous-to-nitrogen imbalance induced when nitrogenous compounds are volatilized during fire, while phosphatic compounds are returned to the soil as ash, may decrease the chances of seedling survival according to Ozanne and Specht (1980).

Wild fires may remove all ground cover resulting in subsequent erosion. Brown (1972) studied the effects of an autumn wildfire on two catchments and concluded that fire had contributed to the total water discharge and an increase in the sediment loads as a result of a thousandfold increase in the rate of erosion over a period of 12 to 18 months after the fire. Good (1973) recorded only fourfold and twentyfold increases in sediment loads over a month for a summer wildfire. Both fires burned similar forests but the initial vegetative recovery after the summer fire was rapid whilst the regrowth after the autumn fire was very slow during the following winter; hence poor vegetative cover predisposed this catchment to erosion from high-intensity rainfall and run-off from snowmelt in the spring.

START INDEX

Summary

From a consideration of the history of fires on the Australian Continent it is very unlikely and cannot be claimed that fires caused the degeneration of the formerly lush rain forests. The most probable cause of the change in vegetative cover is change of climate. Fire nevertheless may have played a supporting role at a crucial period.

The role played by fire in the vegetation hierarchy is very complex. Low-intensity fires promote nitrogen degeneration whilst high-intensity fires sponsor legumes and hence nitrogen enrichment. The phosphate-nitrogen imbalance after a fire can cause seeding failure. Bushfires are a necessary function for regeneration of certain species. However, depending on the subsequent weather the after effects of fire can be quite different. If a drought year follows a bushfire then regeneration of burnt vegetation would be difficult. Competition for vegetation in a drought year would also make survival unlikely. In the absence of significant vegetation wind erosion could be expected to remove the fertile topsoil. A heavy downpour after severe fire damage can also bring about the loss of fertile topsoil. Such loss would promote degeneration of vegetation and could result in desertification.

Areas with marginal rainfall would be the most susceptible to desertification after a fire. Intervention of man after a fire may also cause a fire-ravaged area to be cleared and when the appropriate weather such as drought or extreme rainfall occurs desertification may result.

The husbandry carried out in forest reserves when managed well, results in regular reduction of the forest debris which stops a major conflagration occurring and reduces the risk of fire-promoting desertification.

Grasslands are less conducive to fuel management than forests. As they dry out each year grasslands present a greater danger for fires and possibly consequent desertification than well-managed forests. Certainly a succession of droughts would decrease vegetation on grasslands markedly and make it susceptible to desertification.

Any change in vegetative soil cover by fire may result in a change in the microclimate, which in turn will determine whether a surface will be susceptible to rain or wind erosion, to humus generation and seedling propagation or whether vegetation will be restricted with consequent soil degeneration.

In conclusion it must also be pointed out that fires have beneficial effects also. Some vegetation is promoted as a result of fires and certain fauna benefits when domiciliary habitats are renewed. Diseases and pests can be eradicated when fire affects vegetation. Fire thus can have beneficial effects as a servant but when the atmosphere causes fire to become master, the results can be disastrous both in the immediate future as well as in the long term if desertification results.

3.2 Data requirements

- Fire
- Desertification

3.2.1 Fire

The south-eastern part of Australia is, of course, one of the most fire-prone regions of the earth. Reference will be made here to the Australian methods used to assess the requirements for fire-hazard data.

Weather and climate are the main factors in fire behaviour. Whilst climate determines the quantity and state of fuel, weather determines the daily potential fire hazard. As a result, seasonal meteorological data are useful for assessing the quantity and state of fuel. In addition to the state of fuel, other inputs are forecasts of wind speed, humidity, rainfall (if any) and temperature in the near future.

Data requirements for existing methods

The elements which exert most influence on fire propagation are fuel (quantity and state) and wind (speed). In order to assess the state and quantity of fuel there is a weekly accounting system for key stations. The fire services provide additional data on the state and quantity of fuel. Data on seasonal precipitation and temperature also provide useful information on potential fuel for the forthcoming fire season.

There are many fire-measuring instruments which make it possible to determine the state of fuel, windspeed, temperature and humidity. In Australia, separate instruments (Luke, McArthur, 1977) are used for meadows and forests. In the instrument for forests, a special "drought factor" is used to determine the state of fuel. The drought factor is taken to be a function of air temperature and precipitation; the number of days after the last rain event is also considered. In the instrument for meadows, the state of fuel is taken from direct observations in particular regions. Forecasts are made of windspeed, humidity and maximum temperature approximately at the time of the maximum temperature. This forecast information is introduced into the corresponding measuring instrument for meadows or forests and a forecast value of the fire hazard is obtained. Consequently, the requirements for data on fires now almost completely consist of forecast parameters. A special observation of prolonged fires is introduced with special attention to the structure of wind and heat in the vertical. Jet streams in the troposphere are extremely important. Forecasts of storm probability in forest areas are especially useful as warnings for taking counter-action against lightning fires.

Possible future use of satellite fire-hazard data

At present, point assessments are made of the fire hazard. Radiation fields can be obtained from geostationary satellite data. Correlations between the state of fuel and radiation data using ground-truth data would give the current "field" of the state of fuel.

The TIROS polar-orbiting satellites can be used for obtaining the fields of dew point, temperature and wind at least up to the 850 hPa level at present; boundary conditions prevent the fields from being obtained at the earth's surface. The possibility is not excluded of obtaining representative fields for the approximately 1 000 m level with subsequent determination of surface "fields" by assembling as many surface observations as possible.

After obtaining the "field" of wind, temperature and humidity using the satellite, one can use a forecaster to provide forecast fields of the main meteorological parameters which are needed for determining the fire-hazard field.

Use of satellite data in conjunction with surface data would permit better assessment of the fire hazard. It is often helpful to enlarge satellite pictures in order to determine storm activity more accurately. Frontal activity can be monitored from sequential satellite pictures in order to establish a potential source of storm activity. Lightning recorders are used in conjunction with radar to locate and warn against lightning discharges.

Detection of surface moisture, for example recent rain or dew, would be useful. In arid regions dew can frequently be a deciding factor as to whether a particular type of vegetation can survive.

3.2.2 Desertification

Fire facilitates desertification. Drought on its own helps to exhaust the vegetation and soil, but drought in conjunction with fire speeds up the desertification. Continuous observations must therefore be made of drought in order to be able to issue timely announcements and take recovery measures. In Australia, the drought observation system is based on precipitation deciles (Gibbs, Maher, 1967).

Vegetation is the deciding arbiter of whether it will suffer from moisture deficit. A method for dividing up soil moisture layer by layer according to seasons was developed by Baier and Robertson (1966). If it is possible to test their model according to selected points with actual soil-moisture data, the model can be correlated with the moisture deficit, thus producing useful information on such signs of desertification as the exhaustion of the plant cover.

Fire results in a situation in which the earth's surface is susceptible to erosion whether by water or wind. A representative station network measuring the intensity and duration of precipitation is therefore useful in assessing potential damage from erosion; likewise, a station network with anemometers should provide the necessary wind data. Most wind-finding stations give, amongst other information, mean wind speed, but in this case it is necessary to obtain the arithmetic mean of the cube of wind speed and not the cube of the arithmetic mean speed, according to Duncan (1977), since wind erosivity depends on the cube of the wind speed.

Meteorological data can be used in planning tree planting to protect fields from extreme values of wind and radiation, in order to promote the renewal of vegetation in some areas.

The difference between evapotranspiration and precipitation can be used to determine:

- Degradation of plant cover;
- Exhaustion of soil structure;
- Reduction in the soil's organic matter content;
- Swamping and excess of toxic substances.

In order to monitor these phenomena, it is possible to obtain from satellite data fields of temperature, humidity, radiation, wind and precipitation; these can be used to derive the difference between the fields of evapotranspiration and precipitation, instead of estimates of these parameters for selected points.

Summary

It is important for proper management to have data on the processes which promote fire-inducing weather and desertification.

Application of the newest methods for the analysis of standard satellite data will be able to provide various fields of observations rather than observations at a selected point. As a result, the signs of fire hazard and desertification should be presented in the form of the fields rather than points.

It may well be possible in the future to obtain fields of soil moisture from satellite information as well as to observe or calculate areas of dew formation. Dew may be an important source of moisture in certain cases for arid and semi-arid vegetation as well as, if the presence of moisture is necessary, for the development of disease.

It thus seems that the application of satellite data in conjunction with ground-truth data is the key for future progress in combating fire and desertification.

3.3 References for Section 3

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4. EFFECTS OF PESTS AND DISEASES ON THE PROCESSES OF DESERTIFICATION*

Pests and diseases cause serious damage to crop yields. According to FAO data, insect pests destroy one fifth of the world's harvests, which can be roughly broken down as follows: about 200 million tons of grains, 230 million tons of sugar beet, 30 million tons of potatoes, 2 million tons of vegetables and almost 12 million tons of fruit.

Dozens of types of insects damage all the main crops; for example, there are 40 known types of insects which damage rice, 60 which damage potatoes, about 100 which damage sugar beet, 128 which damage wheat and maize, etc. (Prokofiev, 1982).

In years of heavy and widespread infestations, there is particularly heavy damage to the crops. The history of farming in arid and semi-arid areas includes many tragic consequences of locust invasions. To mention only one of these cases, in November 1889 there was massive breeding of locusts in Egypt. The gigantic "cloud" flew over the Red Sea during the space of a few days and settled in the plantations and gardens in Arabia, completely destroying the flowering oases and green fields. It was calculated that the locust swarm covered an area of 5 967 km^2 and weighed 44 million tons (Prokofiev, 1982).

A great deal of information has been collected on the desert locust (Schistocerca gregaria), the climatic conditions of its habitat and mass breeding, migration routes depending on weather conditions, etc., which the reader can find in the very interesting publication "Meteorology and the desert locust" (WMO-No. 171.TP.85, 1965), as well as in the specialized literature on plant protection against pests and diseases or on general entomology.

Unfortunately, the members of the working group did not have any new material at their disposal on this question, particularly on the characteristics of the agrometeorological conditions favouring the mass breeding of pests and epidemics of disease.

It should, obviously, be noted that chemical plant protection has been rapidly developed since the beginning of the 20th century.

About 10 000 new insecticides are now being tested every year in the different countries of the world. There are now more than 5 000 brands of pesticides whose annual production exceeds 15 million tons and whose area of application covers about 4 million hectares. The efficiency of man's chemical attack on pests is, nevertheless, dropping because many types of insect pests are developing immunity to the insecticides.

Practice shows that the best results are obtained by combining chemical and biological methods for protecting crops against pests and diseases.

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PART III

1. EXPERIENCE OF APPLICATION OF REMOTE SENSING TO ASSESSMENT OF THE STATE AND PRODUCTIVITY OF VEGETATIVE COVER

1.1 Use of aerial multispectral surveys to assess the productivity of desert pastureland and crops*

The main physical background for the remote acquisition of information from agricultural lands is the difference in the energy brightness between natural and man-made plots of the earth's surface. To solve various tasks the whole spectrum of electromagnetic radiation is used, from low-frequency radio waves through metric and millimetric waves used in radars and radiometers, infra-red, visible, and ultra-violet regions of optical spectrum, up to gamma-ray photons of materials.

At present, in the U.S.S.R. and other countries, some experience has already been accumulated on the assessment of the productivity of desert pasture vegetation and crops from photometric and spectrometric measurements in visible and near-infrared regions of spectrum (3, 5, 10-12, 18). The procedure for such an assessment is based on the application of the spectral brightness coefficient of objects, r_λ , by which we mean the ratio of the object's surface brightness in a given direction, B_o, to the brightness of an ideal scattering surface (reference), B_r, at the same illuminance in an individual spectral band.

$$r_\lambda = \frac{B_o}{B_r}$$

The magnitude of spectral brightness coefficients (SBC) of the soil/plant cover depends on a number of factors such as the state and composition of vegetation, soil conditions, light conditions, conditions of measurement, etc. Let us discuss the effect of some basic factors on the SBC value.

Integral brightness coefficients of plant cover are essentially determined by the structural peculiarities of this cover (3, 4, 7, 19). Variations in the nature of reflection between different types of vegetation are above all determined not by properties of leaves themselves but their position inside the sward or forest stand. As the result, the reflectance of vegetation is determined by the number of illuminated plots and shaded spaces between them (3, 23). Maximum optical contrasts in a scene are observed between illuminated and shaded elements.

In photographs in the visible region of spectrum, the illuminated elements of plants and soils appear as light to light grey. All the shaded elements appear as dark grey to dark. The area of half-tones is comparatively small. The regular alternation of illuminated and shaded surface elements has become commonly referred to as the light-and-shade mosaic (LSM).

The smaller the area of shades in LSM, the higher the SBC values of vegetation and the lighter tone of image vegetation has in panchromatic aerial photographic materials. The relationship between the area of shades in LSM and optical properties of plant cover has the form of an exponential curve (3, 4, 19) (Figure 3).

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*by I. G. Gringof and A. D. Kleschenko (USSR)

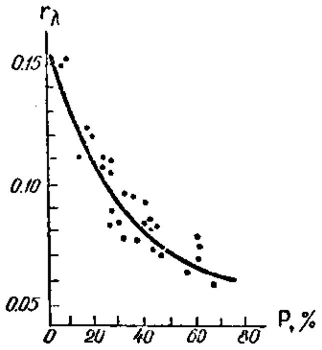

Figure 3 - The form of the relationship between the spectral brightness in the 590-680 nm band and shaded area in the light-and-shade mosaic (%) of a cotton field

The relationship between fields in LSM depends on light conditions and, if those are comparable, on the structure of plant cover and above all on the shaded area on the ground as well as the relevant structural characteristics of a crop stand (density, height, mass, number of layers, leaf area index, etc.).

Figure 4 illustrates the relationship between SBC of plant cover and shaded area on the ground.

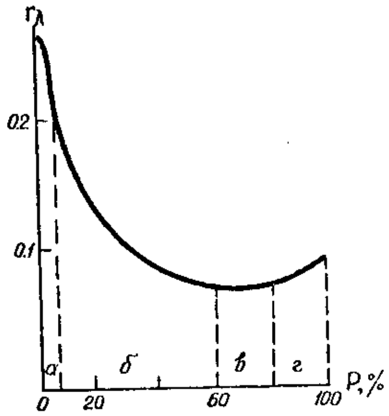

Figure 4 - The generalized form of the relationship between the spectral brightness and design cover, P (%), of the semi-desert semi-shrub vegetation; at h_o = 30-35°, r_λ = 0.25 in the 590-680 nm spectral band

The area of shades in LSM increases with the height of stand, h. As stated in (4, 24), communities of higher plants have lower SBC than those of lower plants with the same cover (Figure 5).

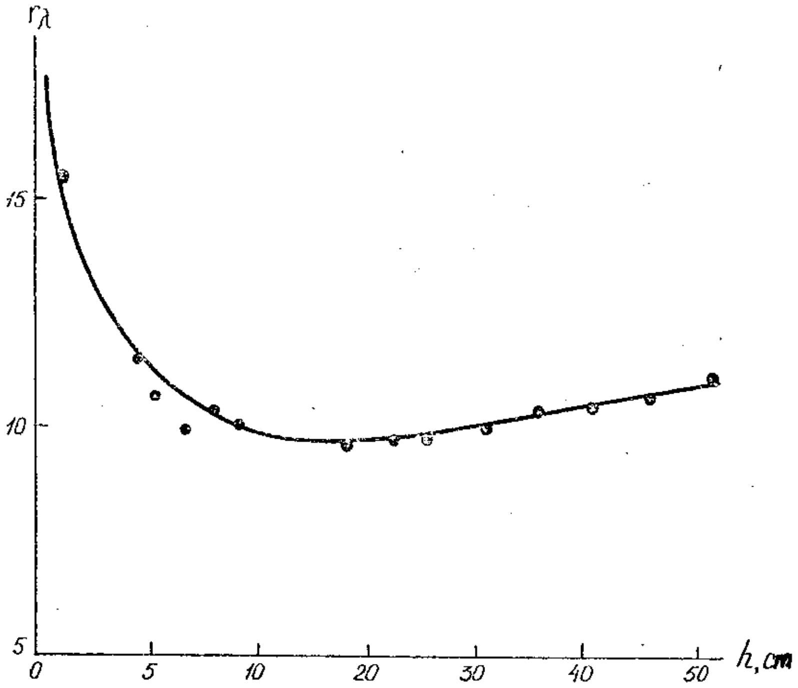

Figure 5 - The form of the relationship between the total brightness in visible spectral region (λ = 475-640 nm) and the height of grass stand in a mixed grass and cereal meadow community

The nature of the dependence of SBC on vegetation changes with the degree of covering. This dependence is best shown at low and moderate values of covering up to 50-60% when soil effects on the integral image are pronounced (Figure 4). With covering of about 60-70%, the relationship becomes less close. Finally, quite a weak relationship is observed in closed communities with significant covering (80-90% and more).

The photometric technique for the determination of the above-ground vegetative mass, leaf area and plant density as developed in the U.S.S.R. is based on the relationship of soil/vegetation system's SBC to plant cover parameters (1, 2). As an example borrowed from (15, 17), Figure 6 illustrates SBC of wheat and alfalfa stands at different values of vegetative mass. The data in Figure 6 were obtained from the results of photometric measurement of Bezostaya-1 wheat stands at the earing stage and alfalfa at the inflorescence stage. The stands were located on a typical sierozem. Photometric measurements were made with a field spectral photometer (9) placed normal to the soil surface at clear sky and sun altitudes of 55-60°. The spectral range of the photometer's sensitivity was 380-900 nm. The spectral resolution in this wavelength interval was 16 nm. The altitude of the photometer's installation was such that the photometer covered a plot of the stand. As a reference, baryta paper with a known brightness coefficient was used. After photometric measurement, the above-ground plant mass on the plots was cut and weighed with a balance to an accuracy of 1 gram. It can be seen from Figure 4 how significantly the amount of vegetative mass affects SBC of stands.

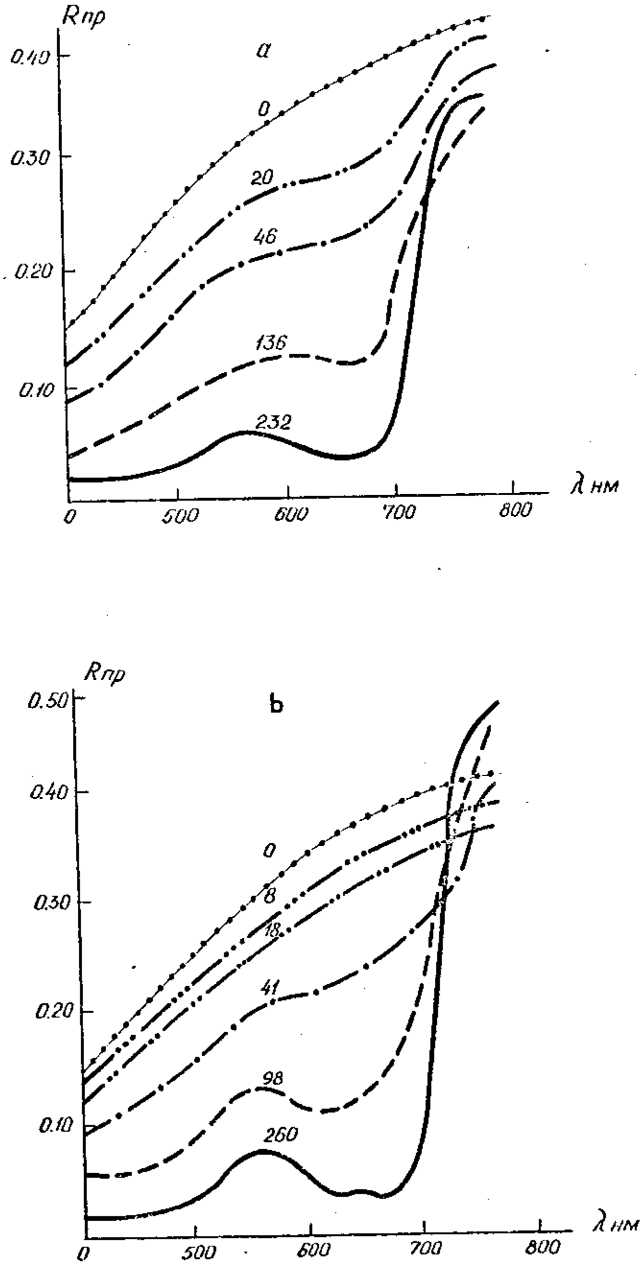

Figure 6 – The curves of spectral brightness coefficients of (a) wheat and (b) alfalfa stands on a typical sierozem. Numbers above the curves are the values of green mass of stands, 100 kg/ha.

The closeness of relationship between reflecting properties of plant cover and some of its parameters and therefore the errors of the technique depend on the degree of contrast in the soil/vegetation system. With contrasts less than 0.15, the relationship between SBC of the soil/vegetation system and plant cover parameters is insignificant. With contrasts of 0.5 and more, the relationship is fairly close.

Under those conditions, in the case when photometric measurement is made in the normal direction to the earth's surface and atmospheric effects are minor, the relationship between SBC and plant cover parameters can be approximated to a reasonable accuracy by the following formula (2, 18):

$$R_{sv} = \frac{R_v(R_v - R_s - 1) + (R_v - R_s)e^{-\beta EM}}{R_v R_s - 1 + R_v(R_v - R_s)e^{-\beta EM}} \qquad (1)$$

where

R_{sv}	is the spectral brightness coefficient of the soil/vegetation system;
R_v	is SBC of the utmost dense plant cover, i.e. a cover that completely shields reflection from soil;
M	is the above-ground vegetative mass per unit area;
β	is the parameter representing the structure and reflecting properties of a given plant cover

$$E = \frac{1 - R_v^2}{R_v}$$

Equation (1) is the transformed formula of Gurevitch (6) and Kubelka and Munk (22) which they obtained in a two-flow approximation under certain simplifying assumptions concerning the light field inside the scattering medium.

The values of β and R_v are constant for a given plant cover. To determine plant cover parameters with formula (1) it is necessary to measure brightness coefficients of the soil/vegetation system (R_{sv}) and of soil (R_s).

Figure 7 represents SBC curves of some soils and a green plant. They allow for the choice of effective wavelengths (those where the maximum contrast between R_v and R_s is observed) which are worthwhile to be used in measurements. For black soils, those wavelengths will be in the range of 500-600 nm, for saddy podzalic soils in the range of 600-650 nm. The wavelength required is selected by means of appropriate photocells and interference light filters.

At present, a number of spectral photometers have been developed for both ground and aerial measurements (9, 10, 12, 20). Figure 8 illustrates the photometer's optical train as described in (10) which is used in both ground and aerial measurements of SBC of soil and vegetation objects. As can be seen from the train, the instrument is a two-beam photoelectric photometer with two photometric heads 1 and 2 of which one serves for measuring reference brightness 3 and the other for measuring object's brightness 4.

The light flow reflected from reference 3 passes inlet 5 of a photometric head, system of diaphragms 6, frosted glass 7, light filter 8, and enters photocell 9. The same is true about the optical train of the instrument's measuring arm. The instrument is fairly simple in both design and operation. In this case, brightness spectral coefficient of the object, R, is determined by the formula:

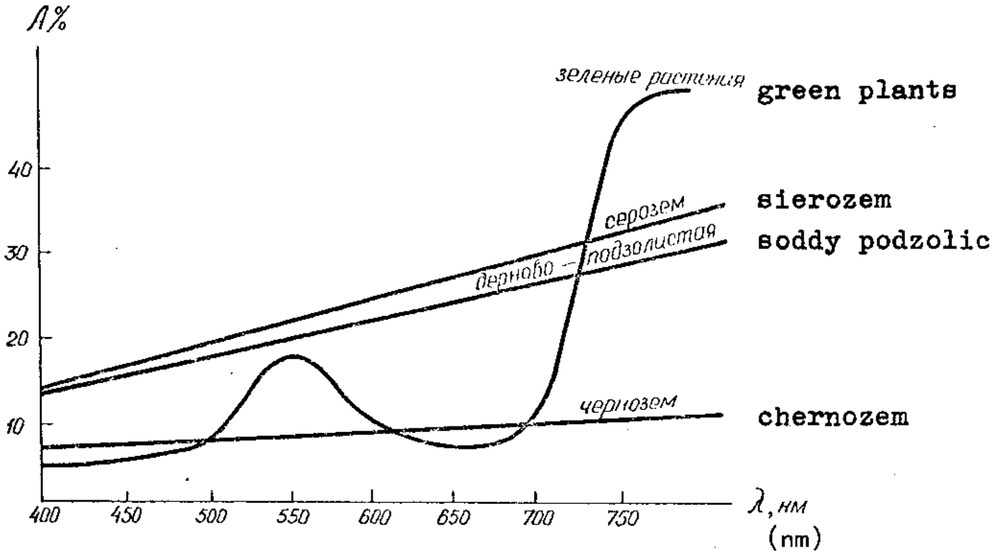

Figure 7 – The curves of spectral brightness coefficients (SBC) of some soil types and green plants

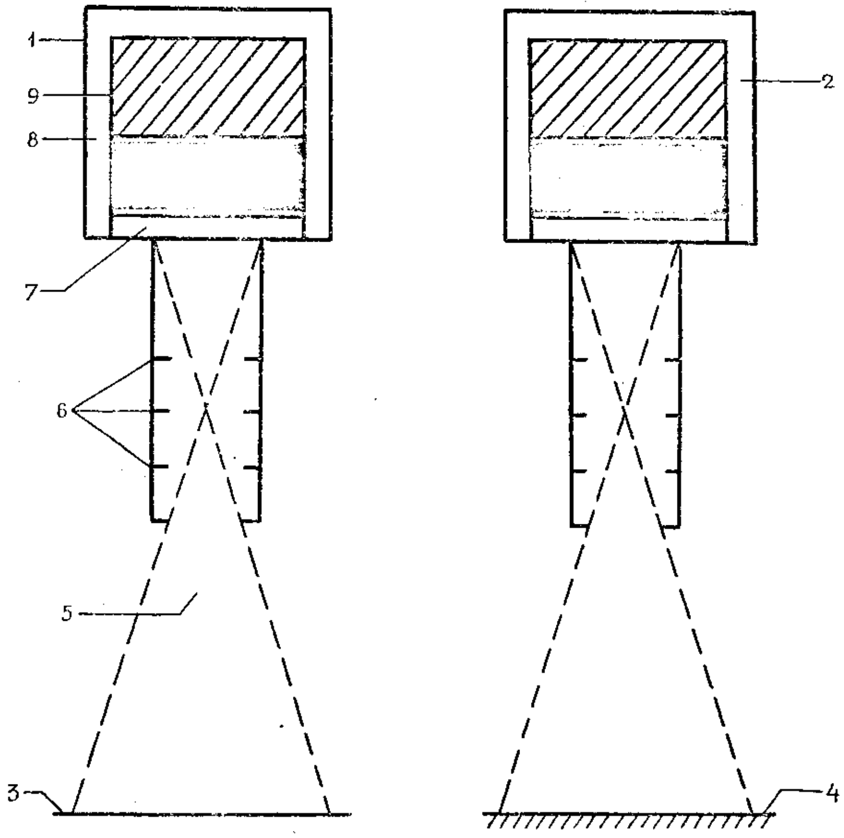

Figure 8 - The photometer's optical train:

1, 2 - Photometric heads
3 - Reference
4 - Object
5 - Inlet
6 - System of diaphragms
7 - Frosted glass
8 - Light filter
9 - Photocell

$$R = R_r \frac{B_o}{B_r} \qquad (2)$$

where

R_r is the known reference brightness coefficient;

B_o is the object's measured brightness; and

B_r is the reference measured brightness.

The angle of view of the instrument is 35°. The instrument is calibrated on the ground by simultaneous measurement of R_{sv}, R_v, R_s, and relevant plant cover parameters (10). To that end, 20-30 plots are selected (1 x 2 m) so as to cover whenever possible the whole range of plant cover parameters for a given plot. Then at each plot, measurement is made of R_{sv}, R_s, and vegetative mass (by cutting) and, when necessary, leaf area and plant density. The value of β is further determined by formula (1) using the least square technique. Then with that value the conversion curve is calculated for different values of R_s and M.

The form of the conversion curve for the determination of corn mass at the stage of paniculation is shown in Figure 9.

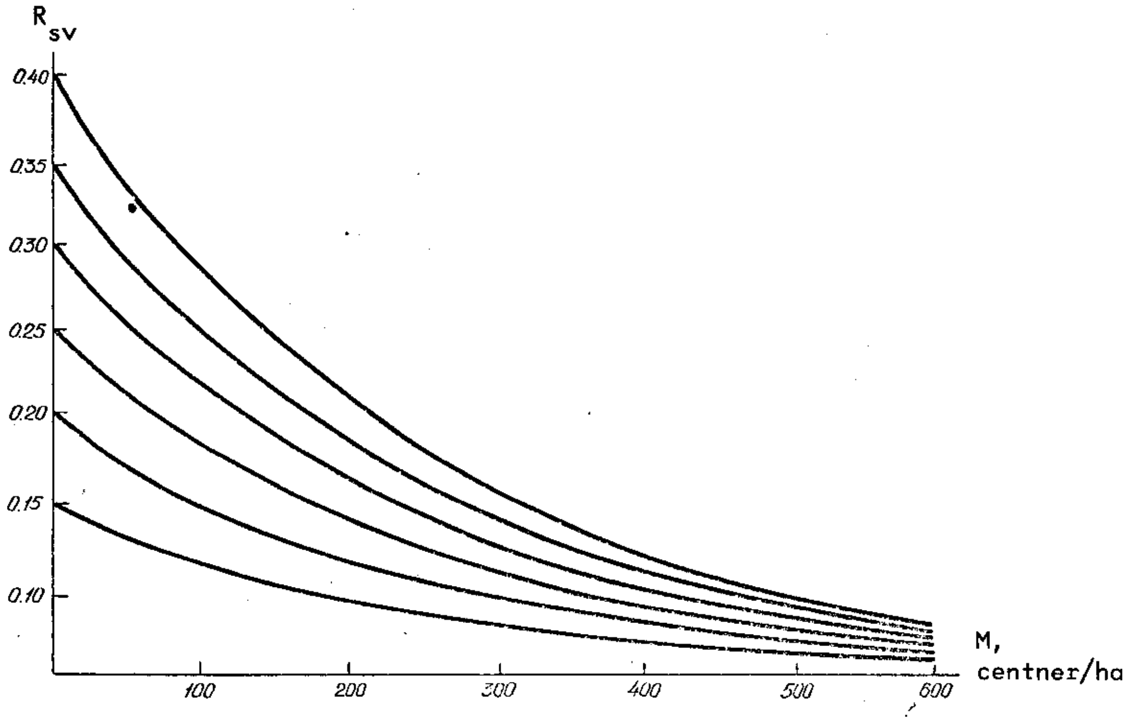

Figure 9 - Photometer's conversion curves for a transition from R_{sv} to M of corn at the paniculation stage. $R_v = 0.05$; $\beta = 0.00025$; $\lambda_{max} = 670$ nm

Such curves are plotted for different crops at individual stages of development. Curves are plotted for sun altitudes no less than 30°C. Further, using those curves in measuring R_{sv} and R_s it is possible to determine plant cover parameters.

As pointed out at the beginning of this section, the relationship of soil/plant cover system's SBC to the soil cover parameters can be affected by soil's brightness coefficient and light conditions. The soil's SBC depends in turn on light conditions, the degree of tillage and soil moisture. While in ground photometric measurements all those effects can be relatively easily accounted for, difficulties may arise in aerial photometric measurements for the determination of soil's SBC in the stand. These difficulties increase in aerial surveys of areas with a high diversity of soil contours. The use of the brightness coefficient ratio in two spectral bands considerably simplifies the conduct of observations for when the sun altitude, moisture, and soil surface conditions change this ratio changes insignificantly (11, 14). The idea of the approach consists in the selection of two spectral bands wherein the investigated object has different absorption. The spectral bands thus selected must be as close to each other as possible so that the effect of side factors on light intensity in these bands is the same whenever possible.

In the determination of plant green mass, it is convenient to employ one spectral region within the chlorophyll absorption band and the other outside it.

The most efficient bands in the spectral regions of 400-1200 nm are those around wavelengths of 670 and 750 nm. The use of $\frac{R_{750}}{R_{670}}$ allows for making measurements from high altitudes since due to the relative closeness of the spectral bands their aerosol coefficients of attenuation do not differ much. The dependence of the SBC ratio of the soil/vegetation system for the radiation with wavelengths near 750 nm and 670 nm (K_{sv}) on plant cover parameters can be expressed to a reasonable accuracy by the formula (11):

$$K_{sv} = K_v + (K_s - K_v)e^{-\alpha M} \qquad (3)$$

where: K_v is the SBC ratio of extremely dense plant cover, i.e. that completely shields reflection from soil, for the radiation with wavelengths near 750 and 670 nm;

K_s is the SBC ratio of the soil under plants for radiations with wavelengths near 750 and 670 nm;

M is the value of the above-ground vegetative mass, 100 kg/ha;

α is the parameter representing the structure and reflecting properties of a given plant cover.

The sequence of steps in the determination of plant mass using the ratio approach is exactly the same as in the case of brightness coefficients (plotting conversion curves, measuring K_{sv} and K_s, and determining M).

At present, regular aerial photometric surveys of desert pasture vegetation and crops at different stages of development are made in the U.S.S.R. from aircraft.

Surveys are normally made at sun altitudes no less than 30° in order to reduce the effect of the sun's elevation on values of the brightness coefficients.

Flight speed of the aircraft is normally 200-300 km/h, the altitude of flight in surveys of desert pasture vegetation being 1000-1500m and in crop stand surveys 150-300m. In so doing, crop varieties are determined visually by the operator from a number of indications. It is the operator who records the beginning and end of measurements in accordance with the length of a field of a particular crop. On board the aircraft, a measuring complex is installed which allows the input data to be recorded in three ways simultaneously (12):

(1) By analogue recording on a diagram tape to control the input data;

(2) By digital printing on a paper tape for operational processing on board the aircraft; and

(3) By punching tape for subsequent processing and analysis at the laboratory.

By now, within the system of the Hydrometeorological Service of the USSR four territorial centres have been established whose surveys cover almost all the regions of the European Territory of the U.S.S.R., Central Asia and Kazakhstan. Based on the results of surveys, a map of the productivity of desert pasture vegetation is prepared and the amount of the above-ground vegetative mass of individual crops by routes or averaged over the area is output.

Maps of desert pasture vegetation yields are used by central agricultural bodies in planning operations in livestock breeding on distant pastures.

The amount of the above-ground vegetative mass as an inertial index finds many applications in the assessment of both crop stand conditions and the expected crop yield. The research done so far indicates that there is a fairly good relationship between the amount of vegetative mass for grain crops at the earing stage and the amount of expected yield (8, 14). The coefficient of correlation varies from 0.75 to 0.85 depending on crop and area considered.

Aerial surveys allow information to be regularly obtained on the distribution of vegetation over the area under survey. Such surveys are particularly important when it is necessary to estimate operationally crop growing conditions in individual regions suddenly affected by adverse conditions.

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2. DETERMINATION OF WATER SUPPLIES IN THE SOIL AND ON THE SURFACE FROM AERIAL GAMMA PHOTOGRAPHS*

In 1962, the technique was invented in the U.S.S.R. for the determination of water supplies in the upper layer of soil and on its surface based on the effect of the attenuation of gamma radiation of natural radioactive elements in soil. This technique has found some application in other countries.

Natural sources of gamma radiation in soil are radioactive elements of the ^{238}U and ^{232}To families and ^{40}K isotope. These radioactive elements occur everywhere in soils and rocks and set up a gamma-ray field in the surface layer of the atmosphere whose intensity, J, at altitude h above the soil surface depends unambiguously on relative soil moisture, W, and water supply on the soil surface, e.g. in the snow cover, p. This relationship is well approximated by the following expression (4):

$$J = \frac{J_o \exp((-\gamma_p - \gamma_h)/k_1)}{1 + kW} \qquad (4)$$

where J_o = J (with p = 0, h = 0, and W = 0) is the value determined by concentrations of radioactive elements in soil; p and h are expressed in g/cm^2; k_1 and k are the coefficients representing the difference in absorbing properties of soil, water, and air; and γ is the coefficient depending on the spectral angular characteristics of the radiation concerned.

In measurements from the altitude of 20-100 m, relationship (5) is followed quite exactly (aerial gamma survey). As this takes place, $k_1 = k = 1.11$. Relationship (5) may be used as a calibration curve to determine the water equivalent of snow at invariable soil moisture. With p = 0, this relationship may be used for the determination of soil moisture. In this case, it takes the form as follows (5):

$$J = J_o/(1 + kW) \qquad (5)$$

The contribution of soil layers located at different depths to the total flow of gamma-ray photons decreases with the depths approximately exponentially. Therefore, the sensitivity of gamma survey to soil moisture changes at different depths also decreases with the depth. Actually the whole radiation measured is emitted by the upper soil layer 30-40 g/cm^2 wide (approximately 30-40 cm), thus predetermining a possible depth of measuring soil moisture with the help of gamma survey.

To determine the soil moisture along particular routes it is required to determine the value of J_o, i.e. the intensity of gamma radiation of dry soil in the 30-40 cm layer for a given route. Referencing can be made in another way, namely simultaneous measurement of gamma radiation intensity, J_1, and soil moisture, W_1, of the investigated object. In this case

$$J_o = J_1/(1 + kW_1) \qquad (6)$$

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*by M. V. Nikiforov (USSR)

Substituting expression (6) into (5) we obtain the following relationship for (4):

$$W = \frac{J_1}{J}\left(\frac{1}{k} - W_1\right) - \frac{1}{k} \qquad (7)$$

i.e. further measuring gamma radiation intensity, J, it is possible to trace the soil moisture dynamics. The instrumentation complex for aerial measurements involves two detectors of gamma-ray photons which are scintillation NaJ (TL) monocrystal counters 150 mm in diameter and 100 mm high placed into steel collimators. One of them is intended to measure gamma radiation from below (from the object) within the angle of a 150° spread and the other from above within the cone of a 50° spread. The complex then involves digital recorders (counters) to record the radiation measured; radio altimeters to measure flight altitude; two pulse analysers provided with systems for stabilizing the energy scale according to the photopeak of the ^{40}K radiation with an energy of 1.46 MeV. The width of the ground strip covered constitutes two or three flight altitudes.

Table 17 shows the results of comparative measurements of soil moisture by means of aerial gamma survey and thermostat weighing technique for different soils and crops (2, 5). To that end, measurements were made of gamma radiation intensity on the investigated fields from which the value of soil moisture was further calculated. At the same time, on the same fields ground-truth measurements were made at 40 points for each route. Random discrepancies between the value of soil moisture as obtained by means of gamma survey and that obtained from ground-truth measurements (averaged over 40 points for each route) are shown in Table 17.

Table 17 indicates that quite reliable data on soil moisture over large areas can be operationally obtained by means of aerial gamma survey. The results of such operational surveys are used for the assessment of the state of crop stands and their moisture conditions for the purpose of determining the irrigation terms on irrigated lands.

In the U.S.S.R., aerial gamma surveys of snow water equivalent are also regularly made. The results of such surveys are used in making forecasts of river floods and for the assessment of water supply in soil by spring.

The survey procedure boils down to aerial measurements of count rates from the recording of gamma radiation flow of soil over snow-measuring (water-measuring) routes with the division into three landscapes in snow surveys (wood, field, shrubs) and into three crops (winter, spring, tilled) in moisture surveys. The change in intensity from survey to survey is completely attributable to the change in snow water equivalent in winter and in soil moisture in summer.

The level of instrumental techniques for surveys attained in the U.S.S.R. provides the accuracy of measurements of snow water equivalent in plains with a stable snow cover and supplies up to 300 mm of 8-9 while in mountains with snow water equivalent up to 600-700 mm the accuracy is 10% and 1-2% on particular fields.

Table 17 - Random discrepancies (percentage of moisture) between the values of soil moisture obtained by means of aerial gamma survey and ground-truth techniques

Crop	Soil type	Length of route, m	%
Potato	Soddy podzolic - middle loam	900	0.9
Winter wheat	Soddy podzolic - middle loam	800	0.8
Potato	Soddy podzolic - middle loam	900	2.5
Potato	Soddy podzolic - middle loam	800	1.1
Barley	Soddy podzolic - middle loam	2 000	0.4
Winter wheat	Soddy podzolic - middle loam	700	0.9
Winter wheat	Soddy podzolic - loamy sand	600	1.1
Winter wheat	Soddy podzolic - loamy sand	600	1.1
Winter wheat	Soddy podzolic - light loam	800	1.5
Potato	Soddy podzolic - middle loam	900	0.5
Potato	Soddy podzolic - middle loam	500	0.9
Potato	Soddy podzolic - middle loam	600	0.5

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3. APPLICATION OF LANDSAT DATA FOR NATURAL RESOURCE INVENTORY AND MONITORING OF DESERTIFICATION*

The report by K. A. Shankarnarayan and S. Singh, "Application of Landsat data for natural resource inventory and monitoring of desertification" (South Dakota State University, Brookings, South Dakota, U.S.A., October 1979) has demonstrated the feasibility of the application of Landsat imagery for:

(1) Visual interpretation of natural resources of Rajasthan (India) and surrounding regions on a false colour composite mosaic;

(2) Semi-detailed mapping of earth resources and monitoring of desertification from one scene covering the Middle Luni River Basin by both visual interpretation and digital analysis. Pictorial and visual interpretation of Landsat imagery has been used for the assessment of earth resources on a regional basis over vast areas. The first approach is to observe the difference in the grey levels in the four spectral bands or to use colour composite enhanced images produced by a combination of the ERTS pictures.

Success of Landsat imagery interpretation begins with acquiring cloud-free or at least less than 10% cloud cover Landsat scenes of the study site.

The second approach involves semi-detailed mapping of earth resources by computer analysis and is referred to as the digital approach. The four bands of data are spatially recorded and stored on magnetic tapes in computer-compatible tape (CCT) format.

Considering that the digital approach has the limitation of covering only one small subscene at a time, and in view of the expensiveness of hardware and software (for India), the digital approach was confined to two stratified small subscenes for estimating range biomass and distribution of vegetation, land forms, soil and water bodies.

Two options existed in selecting Landsat scenes:

(1) Viewing the microfiche on a display screen;

(2) Viewing a detailed printout of the selected scene on given dates, if the season was used as a parameter.

Both temporal and multispectral scenes were viewed simultaneously with the aim of reaching interpretive decisions for timely diagnosis of desertification indicators so that appropriate measures could be taken to combat the process.

For semi-detailed study of the earth's surface features an interactive multispectral image processing and analysis system, the General Electric 100, was used. This system utilized a PDP-11 series computer with standard peripherals. Computer printout, cathode ray tube and film positive options were available for display of classification results. The console screen displayed 512 x 512 pixels.

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*by I.G. Gringof (USSR)

Results

1. Mapping of earth's surface features

Visual interpretation of the Landsat false colour composite mosaic of Rajasthan in conjunction with the ground truth data led to the identification, delineation and mapping of nine geomorphic units, from mountains to sandy plains.

Semi-detailed interpretation of one Landsat scene (16 January 1977, 1:250 000) led to the recognition, delineation, and mapping of 16 geomorphic units.

Semi-detailed study of the imageries indicated that the earth's surface features are among the most observable resources on the imagery in all multispectral bands, band 5 image providing a clear view of topography and slope.

2. Soils

The USDA World Soil Geography Map provided the basis for the interpretation of Landsat mosaic and delineation and mapping of soils. Use of the Landsat imagery permitted refining the soil boundaries. The false colour mosaic enabled efficient regrouping of soils having similar tonal and textural characteristics.

Twenty-two soils were distinguished from the Landsat false colour mosaic of Rajasthan and surrounding areas on the basis of information from USDA World Soil Geography Map in conjunction with landform features.

Except for a broad differentiation into light and heavy textured soils, the soils in general could not be interpreted directly from the Landsat imagery (16 January 1977, 1:250 000). Nonetheless, it was amenable to interpretation in conjunction with the landforms. Eleven landforms and their associated soils have been delineated, mapped and described.

3. Vegetation

Vegetation, like soils, is not discernible from a false colour composite mosaic alone. However, when used in association with information on relief and ground truth data, such mosaics permit the delineation of four broad vegetation types.

It has been shown by a number of scientists that Landsat pictures can be used effectively for mapping vegetation in intensive farming regions.

In the present study an attempt was made to determine if the information content of Landsat imagery of arid regions was sufficient to map desert vegetation.

Desert vegetation, like soils, cannot be detected directly from satellite pictures at the present levels of resolution. However, it is possible to locate areas of the main types of vegetation from relief and ground truth data.

Band 5 and 7 black and white images and/or false colour composite imagery thus permitted efficient interpretation and mapping of the desert vegetation. However, the interpretation of band 5 is more difficult with regard to vegetation on medium and heavy textured soils and on wet soils. In such cases the band 7 black and white and false colour composite images helped overcome the problem of differentiating the vegetation from the soils.

Eight types of soil and vegetation have been identified in this way. In the intensively cropped areas in the dry cool season it is rather difficult to distinguish between natural vegetation and cultivated crops. This problem is solved by temporal analysis of false colour composite images.

4. Water resources

The false colour mosaic (1:1 000 000) and the colour transparency (1:4 000 000) permitted efficient mapping of the drainage system of Rajasthan. Four major drainage systems were recognized in this region. There are many indications that Landsat data provide valuable information on water resources.

Surface water resources are easily discernible in all the four spectral bands. Band 7 clearly demarcated the water bodies from the surrounding regions, band 6 indicated the presence of algae and phytoplanktons, while bands 4 and 5 permitted a quantitative assessment of sediment and depth, respectively.

The surface area of water bodies was determined on a multitemporal basis using a 70 mm lantern projector. To this end, the area containing water bodies in the 9" x 9" black and white transparencies of band 7 was carefully cut out into 10 cm x 7.5 cm pieces, mounted in aluminium frames of 8.1 x 10 cm and placed between two thin transparent micro-cover glass plates. The image of water bodies cast on the screen was traced and the area calculated on Numonic Electronic Graphic Calculators.

Evaluation of groundwater potential by visual interpretation of the false colour composite in conjunction with band 5 and 7 black and white images established two groundwater potential zones, viz. the donor zone and the receptor zone.

In all the spectral bands of the images of the receptor zone vegetation is conspicuously absent, indicating saline water conditions.

5. Land use

Multispectral scenes were used for evaluating land use in both irrigated and non-irrigated areas. The false colour composite consisting of imagery for January 1973 and January and February 1977 was interpreted for present land use.

The false colour composite image appears eminently suitable for delineating and mapping present land use. Cultivated land appears in light to dark red, whereas fallow land appears bright to dark green.

Seven major land use units were delineated and mapped on irrigated crop lands and four major land use units on rainfed (non-irrigated) crop lands.

6. Interpretation and mapping of aeolian features

The sand dunes appear very prominently in band 5 black and white imagery. Five types out of the previously revealed 6 types of dunes were easily observed; only the barchan dunes could not be readily identified.

The Landsat band 7 imagery of the dry cool season was found eminently suitable for distinguishing the stabilized dunes from the active ones. The stabilized and active dunes have been successfully delineated and mapped from the imagery.

Summing up the results of the research, the authors emphasize that digital analysis of the Landsat multispectral data permits successful solution of the following problems:

(1) Digital analysis of multispectral data facilitated further quantification of natural resources. Comparison of the digitally generated map with that developed from ground data revealed good correlation of spectral classes to integrated land units described by land surveys.

Reflectance characteristics of certain types of relief result from variations in moisture regime, vegetation, slope and runoff. Thus the reflectance characteristics of different landform types may be similar. Digital mapping of the units may precede field work and act as a guide to the field sampling and detailed terrain unit description.

(2) The present research indicates the feasibility of the range biomass quantification from the Landsat imagery for various soil series identified from ground data on the basis of digital analysis of the Landsat multispectral data.

(3) The band 5 computer overstrike printout permitted spectral differentiation (pixels with similar grey levels were grouped together) as well as classification and accurate delineation of the distribution of six vegetation classes in six grey levels.

(4) Based on the spectral characteristics expressed in terms of dark and light tone pixels in the band 7 computer overstrike printout, it was possible to delineate and map the distribution of sand dunes, interdune plains and water bodies. At the same time their distribution area was quantified and expressed as percentage.

(5) Remote sensing techniques have been of great value in the monitoring of desertification. Based on the tonal and textural characteristics of the Landsat false colour mosaic, it was possible to assess the development and distribution of sand-free and sand-affected areas, as well as to improve our knowledge of the probable desert spread.

(6) The study of the band 5 black and white scenes (1:250 000) led to the identification, delineation and mapping of desertification processes, such as wind deposition and deflation, water erosion, natural and man-induced salinity hazards.

(7) The band 5 computer overstrike printout map of one of the sub-scenes helped to assess the vulnerability of the given region to desertification, and to delineate and estimate its area.

3.1 Reference for section 3

Shankarnarayan, K. A., S. Singh: Application of Landsat data for natural resource inventory and monitoring of desertification. A report prepared while in training at: Visiting International Scientist Program (VISP), Remote Sensing Institute, South Dakota State University, Brookings, South Dakota 57007, October 1979.

4. APPLICATION OF SATELLITE IMAGERY TO THE STUDY OF DESERT AREAS*

Lately there has been growing application of satellite data in natural resource studies using the data collected by the Soviet "Meteor" satellites, "Salyut" orbital stations and "Soyuz" spaceships, as well as by the American "Tiros", "Nimbus" and "Landsat" satellites (7, 8, 9, 11).

Satellite imagery has a role to play in the monitoring system, and that is to detect changes occurring in the natural conditions over the study area. If these changes are followed by variations in the optical properties of the earth surface features, and the area size exceeds the spatial resolution threshold of the system applied, the changes may be recognized from the imageries. Depending on the rate of the processes taking place the data must be taken at different intervals.

To obtain imagery with high information content the season must be taken into account as well as the choice of appropriate technical parameters of the survey equipment. The parameters considered are spectral bands, the detector type and sensitivity, etc. Since the detector responds to the earth-reflected solar radiation or radiation emitted by an object, for the technical parameters and natural conditions of remote sensing to be chosen properly, the reflecting properties of the objects surveyed and these properties' temporal and spatial dynamics should be known.

Based on the study of reflectivity and phenology of major scenes of Turkmenistan, several phenological indicators have been proposed for aero-space surveys. These phenoindicators make it possible to determine the commencement and termination dates of the survey periods. Table 18 shows the principal indicators to be used for the establishment of the survey dates in any single year.

Due to considerable year-to-year variability of phytophenological phenomena (ranging up to 10 days and more) under the desert conditions, it is rather difficult to plan the satellite survey dates well in advance, several months prior to the survey commencement. The authors propose regular times for the satellite survey to be carried out in any year. The survey period commencement and termination dates have been established with due regard for the year-to-year variability, and presented in Table 19. It is recommended that Table 19 should be used for the early planning of survey times. In case agrometeorological forecasts are available, these times may be adjusted with allowance for the occurrence of the corresponding stages of the indicator plants presented below.

The sun altitude is of considerable significance for the image quality in remote sensing. When the sun is low the image information content is higher in the imagery of even terrain. In fairly unbroken relief, low-sun images of sandy deserts are more readily interpreted due to the prevailing 10°-25° angles of inclination. The angle of repose for sand is 32°. Under the sandy desert conditions it is advisable to carry out aerial photography with the sun elevation range of from 10° to 20°, and satellite survey with a range of from 20° to 30°. For hilly country the optimum elevation range is 20° to 30° (for aerial and satellite survey) and for highlands it is 30° to 40°.

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*Summary of a paper by Kharin N. G., Radziminsky P.Z., Kurbanmuradov K., Kiriltseva A.A., "Проблемы освоения пустынь", No. 4, 1980.

Table 20 shows technical parameters and natural conditions for aero-space surveys conducted with the purpose of solving some problems characteristic of deserts. It is based on numerous studies of the desert zones' reflectance and published sources (1, 4, 10). Apart from the optimum times for the satellite surveys and the sun elevation, the table also shows the survey periodicity requirements (for solution of certain problems), spectral bands, the sensor sensitivity requirements and the image's spatial resolution. The survey periodicity must be decided upon depending on the life time of the object or event studied.

Table 18 - Phenoindicators of the commencement and termination of satellite survey periods

Geographical region	Season	Phenoindicators	
		Commencement	Termination
The Karakum	Spring	Start of growing of *Haloxylon persicum* (10 days after the phase's start)	Drying of *Carex physodes*
	Autumn	Ageing of fruits of *Haloxylon persicum*	Seed shedding of *Haloxylon persicum*
Hill country Badkhyz	Spring	Start of blossoming of *Remeria sp.* and ephemers	Drying of *Carex pachystilis*
	Spring	Soft dough stage of *Hordeum sp.*	Full maturity of wheat
Cultivated landscapes	Autumn	Opening of cotton bolls	Start of leaf-fall of *Armeniaca vulgaris*

Table 19 - Regular periods for satellite survey of Turkmenistan territory

Geographical region	Optimum period for survey		
	Commencement	Termination	Length
South-east Karakum	20 March 20 September	20 April 30 October	32 days 40 days
Central and Zaunguz Karakum	1 April 1 October	25 April 10 November	25 days 40 days
Badkhyz hill country	5 April	25 April	20 days
Cultural landscapes	15 May 1 October	30 May 30 October	15 days 30 days

Table 20 - Recommended technical parameters and natural conditions for satellite survey

Problems to be solved	Survey month(s)	Sun elevation, degrees	Survey periodicity, months	Spectral bands, nm	Sensitivity, γ and $\Delta\gamma$, min.	Spatial resolution	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Study of relief							
Physiographic division and drawing up of maps	April	20-30	120	600-700			
				750-850	0.05	50	
Geomorphological structure	April	20-30	60	600-700			
				750-800	0.05	50	
Anthropogenic changes	April	20-30	36	600-700			
				750-800	0.05	50	
Study of soil cover							
Regionalization and drawing up of maps	April	20-30	120	600-650	0.05	10	
Salinity and waterlogging	April	20-30	36	500-550	0.10	10	
				700-800	0.10	10	
Study of plant cover							
Drawing up of geobotanical maps and investigation of biological productivity and habitats	April to October	20-30	120	400-525	0.05	10	Sandy desert
				600-675	0.05	10	
				400-500	0.05	10	Hilly country
				625-675	0.05	10	

Table 20 (continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Phenology	January-December	20-30	1	600-700	0.05	10	
			Study of water resources				
Runoff formation; evolution of river, channel and water reservoir beds	January-December	20-30	1	600-675	0.10	5	
				700-1100	0.10	5	
Hydrological mapping	January-December	20-30	1	600-675	0.10	5	
				700-1100	0.10	5	
			Study of pastures				
Species composition, productivity, mapping	April	20-30	60	400-525	0.05	10	Sandy desert
				600-675	0.05	10	
				400-500	0.05	10	Hilly country
				625-675	0.05	10	
Pasture conditions; pasture management system	April	20-30	12	400-525	0.05	10	Sandy desert
				600-675	0.05	10	
				400-500	0.05	10	Hilly country
				625-675	0.05	10	
			Study of soil erosion				
Wind erosion	January-December	20-30	1	500-650	0.05	5	
Water erosion	January-December	20-30	1	700-1100	0.10	5	

The surveying equipment sensitivity is determined by the equipment capability to record the minimum radiation or its variations. The table shows the minimum values and variations of BSC of natural objects which are to be recorded by the detector.

First of all one should emphasize the significance of satellite data for the desert zone scene research. Based on the imagery of plains and lower highlands the scene structures are interpreted, ranging from natural landmarks to physiographic regions and provinces. This makes it possible to carry out interpretation at the scene genus level and sometimes detailed to the scene facies. The above-mentioned satellite data distinctions render the imagery indispensable when carrying on various applied geography research works.

The photographic image pattern in the satellite data is plotted as a result of the integrated image of scene components having different spectral brightness. The greater the difference in picture element (pixel) brightness, the greater the contrast of the imagery (for instance, in the image of a cultivated landscape).

The following characteristic image patterns may be recognized in the satellite imagery:

- Cultivated landscape with sharp tonal variations of wet and dry fields, irrigation channels, roads and other features;
- Complex of ridges and takyrs is sharply discriminated due to the darker sand ridges and lighter takyr stripes;
- Light spots in the vicinity of wells (South-east Karakum);
- Low contrast spots of the sandy desert (Central Karakum);
- Characteristic sand and gypsum desert relief (Zaunguz Karakum, etc.).

During revision of thematic maps compiled from satellite imagery the following problems can be solved: to improve accuracy of the geographic base of the maps (hydrographic network, water bodies, coastal lines of seas, etc.); to read special information from the maps (borders of plant classifications, land types, etc.); to define human activities (pasture overgrazing in the vicinity of wells, forest clearing, etc.); to determine environmental conditions requiring that urgent measures be taken (water reservoir contamination, presence of active sand masses, etc.).

Physiographic interpretation of satellite imagery is based on studying pixels whose size depends on spatial resolution and sensitivity of survey detector. These pixels are able to form a definite pattern of an image, which is to be studied for the topography configuration to be identified. It is practically impossible to study the small intersected relief of desert areas in satellite imageries by means of a stereomodel.

It is to be noted that if the linear strikes of the aeolian relief forms are well marked (ridges or a relief complex with prevailing ridges), they are interpreted comparatively easily. If the topography is constituted by small craters or depressions, these forms render their recognition difficult due to their small dimensions.

The authors have used the satellite data for studying vegetation cover which forms part of any photographic image formation. The role of the satellite imagery is especially significant for the investigation of vegetation of almost inaccessible desert areas. It renders the investigation of the composition and structure of plant communities, complex vegetation pattern and the degree of man-induced effects more efficient than by other means. Besides multi-purpose geobotanic maps, compiled on the satellite imagery can be specialized (applied) maps, in particular pasture maps.

In making corrections of the existing pasture map, the classification of Nechaeva and Nikolaev (2) and Nikolaev et al. (3) was used. As is well known, the problem of pasture resource inventory involves delineation of individual pasture categories, the area of pasture plots, the species composition of pasture vegetation, forage reserves and the extent of pastoral farming development over individual types of pasture. In studying pastures as well as in the inventory of other natural resources the image interpretation is one of the stages in the system of multi-stage cognition of regularities of nature.

In the greater part of satellite images the differences between pasture classes are readily observed, e.g. the sandy desert pastures differ sharply from the gypsum or clay desert pastures on takyr soils. In all cases the river valley pastures and hay-cutting areas are easily distinguished by a complex of features. Further subdivision of pastures within the classes is more difficult.

In a number of cases pasture overgrazing is readily distinguished from the satellite imagery. The study of the Salyut-4 imagery (6) has shown that local patches of desertification are most characteristic of the vicinity of wells, farms and watering points, where herds are concentrated. These patches appear as light circular areas. Patches of desertification are most easily identified in the two regions: South-east Karakum (south of the Karakum Canal) and the Tedjen-Murgab Interfluve. It is to be noted that the mean size of the patches is similar over both regions, 2.16 km and 2.21 km respectively. In the latter of the two regions the patches of desertification near the wells have been identified from the Soyuz-22 imageries. Band 3 (580-620 nm) and band 4 (640-680 nm) have proved to be the most informative out of the six spectral bands studied. It should be emphasized that recognized in these bands with greatest sharpness are boundaries between the pasture areas and natural reserves where anthropogenic activities are limited. These territories appear as dark grey or dark tone.

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5. APPLICATION OF SATELLITE IMAGERY TO THE STUDY OF DESERT VEGETATION PHENOLOGY AND EROSION PROCESSES*

The most efficient method of plant phenology investigation is the application of multispectral satellite imagery permitting the image analysis in separate spectral bands.

Currently the following major methods of interpretation of satellite imagery are available (9): visual interpretation with the use of certain instrumentation; integrated image analysis based on preparing false colour composite prints and using various instrumentation and visual assessment; automated interpretation with the assessment of optical densities of the image and partial visual analysis.

In the present investigation Meteor satellite imagery has been used. The method applied may be referred to as "the monoscopic binocular multiple interpretation of multispectral imagery". For the investigation of phenology the scenes of the territory of Turkmen SSR with repetitive coverage over the period of 1976-1978 have been used. Cloud-free scenes covering the entire area of the Turkmen SSR or its greater part with the optimum orbit-inclination angle have been selected out of a great variety of imagery.

Taking into account the low resolution of Meteor imagery, the study of plant communities was carried out only at the vegetation type and formation levels during different seasons.

To this end identified on the scenes were the following communities: (1) *Nitraria schoberi*; (2) desert thallogens on takyr soils; (3) *Artemisia kemrudica*; (4) *Haloxylon persicum*; (5) *Haloxylon ammodendron*; (6) *Calligonum setosum*; (7) oasis vegetation; (8) *Halocnemum strobilaceum*; (9) *Salsola gemmascens*; (10) *Artemisia bandnusi* and (11) *Salsola richteri*.

Negatives were viewed under the interpretoscope using the grey scale. The following grey tone ranges were visually studied: (I) light; (II) very light grey; (III) light grey; (IV) grey; (V) slightly dark grey; (VI) dark grey and (VII) dark.

As the negatives are studied, one should bear in mind that the natural objects with the least spectral brightness appear in the imagery as the lightest tone, and the natural objects with the greatest spectral brightness appear as dark tone, whereas in the contact prints the reverse relation is observed.

In every version of the survey the image tone was used to identify the objects. Based on the results of such interpretation the optical density histograms were plotted and Table 21 was constructed. Table 21 shows sets of objects grouped in accordance with the image tone which is the same for each set. The Roman figures I-VII represent the above-mentioned grey-tone ranges and the Arabic figures 1-11 stand for the above plant communities. The number of sets identified is a measure of the image contrast. The greater the number of sets, the better information properties the image has. The greatest number of sets out of all the imagery analysed was recognized in the scenes obtained in May 1976. In these the 0.8-1.0μm band was the most informative with six sets of objects easily identified by contrast.

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*Summary of papers by Kiriltseva A. A. and Serkhenov E. published in "Проблемы освоения пустынь", № 4, 1980

The following analysis was carried out to determine the feasibility of identifying each plant community on the background of the other ones. Every plant community was compared with the other ones by the image tone. Eleven formations were analysed, which resulted in 55 combinations with two formations in every one. The higher the combination percentage that would be recognized by the image tone, the higher the information content of the scenes. The results of this analysis are presented in Table 22. It shows the percentage of the pair combinations where image tone differences are registered. Out of the four spectral bands used for data collection in the satellite survey the 0.8-1.0μm band is most informative in the spring season while the 0.6-0.7 and 0.7-0.8μm bands in other seasons.

Table 21 - Sets of objects having the same image tone in the meteor imagery

Date and coverage of the scene	Spectral bands, μm			
	0.5-0.6	0.6-0.7	0.7-0.8	0.9-1.0
26.5.1976	II -1,3,5,6,10 III-7,11 V -2,4,8	II -3,4,5,7 IV -6,10,11 V -1 VI -2,8 VII-11	II -4,5,7 IV -3,6,10,11 V -1 VI -2,8 VII-9	II -5,7 III-3 IV -1,6,11 V -4,10 VII-9
26.8.1976	II -7 IV -3,4,5,6,10,11 V -1,8,9 VI -2	II -7 IV -4,5,6,10,11 V -1,3,8,9 VI -2	III-7 IV -4,5,6,11 V -2,8,9,10 VII-1,2	I -7 IV -4,5,6,11 V -1,3,10 VI -2,8,9

Table 22 – Assessment of interpretation properties of the Meteor satellite imagery

Date of the scene	Number (first figure) and percentage (second figure) of pair combinations differing by visual contrast			
	0.5–0.6 µm	0.6–0.7 µm	0.7–0.8 µm	0.8–1.0 µm
26. 5.1976	55/82	55/82	55/82	54/88
27. 8.1976	55/66	55/71	54/79	54/79
5. 9.1976	–	36/69	30/80	28/82
13. 4.1977	9/88	10/80	12/92	12/92
16. 6.1977	51/72	55/12	–	55/12
11. 8.1977	–	55/12	–	55/12
26. 9.1977	55/67	55/67	52/32	51/11
25.12.1977	21/81	20/70	20/70	20/35
20. 3.1978	20/50	–	–	21/29
29. 7.1978	44/64	20/50	–	54/57
5.10.1978	–	43/55	55/34	55/35

6. USE OF SATELLITE INFORMATION TO ASSESS DESERT PASTURELAND YIELDS IN REMOTE AREAS OF CENTRAL ASIA AND KAZAKHSTAN*

The large-scale application of the aerial photometric technique for the determination of the state and productivity of desert pasture vegetation and crops permits the use of space-based data obtained from the Meteor earth satellites.

The Meteor data with ground resolution of 0.3-2.0 km allow the state of pasture vegetation over large areas to be operationally evaluated to an adequate accuracy, saving considerable amount of labour and is thus economically advantageous.

To use the photometric technique in space surveys, a set of additional ground-truth and airborne measurements is required, involving subsatellite aerial experiments, plotting of calibration curves, etc.

Direct use of the photometric technique to determine plant cover parameters from space is complicated by atmospheric effects, anisotropy of reflecting properties of terrestrial objects as well as by different sun altitudes in different points of the area surveyed.

To eliminate atmospheric effects, subsatellite reference calibration is used. This consists of the establishment of a relationship between the satellite signal corresponding to brightness values of reference objects and their brightness coefficients, and extending this relationship to the whole photographed area. Such a signal can be converted into the image which is recorded on film, or into digital form to be recorded on magnetic tape.

In the first case, a relationship is established between optical density or transparency of the imagery of reference plots and their brightness coefficients and in the second case, between the digital value of object/atmosphere brightness and brightness coefficient of the object.

To determine the state and productivity of pasture vegetation, the results of satellite surveys obtained on clear days with stable atmospheric conditions over the area concerned are used. Atmospheric conditions over the investigated area are evaluated from the results of the analyses of synoptic charts.

For operational purposes, satellite information converted into the image and recorded on film can be used as well as that converted into digital form and stored on magnetic tape.

When using satellite data recorded on photographic film, processing consists in photometric measurement, i.e. measurement of optical density or transmission of the image of the working area only (Figure 10). Prior to the photometric measurement, the image of the working area in a satellite photograph is broken up into elements (Figure 11). For pictures having a ground resolution of 1-3 km, the size of elements should correspond to a square with a side of 30-50 km in the field. Breaking up into elements is made with the help of a measuring grid which is a net of meshes representing equivalent areas in the field taking into account the scale distortion due to the curvature of the Earth.

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*Summary of papers by V. I. Rachkulik and M. V. Sitnikova (Gidrometeoizdat, 1980).

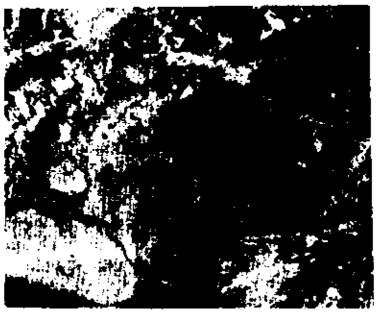


Figure 10

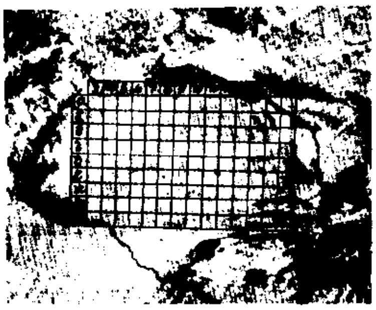


Figure 11

Figure 10 - The image of the Kyzylkum Desert obtained on 7 May 1975.

Figure 11 - The image of the Kyzylkum Desert with the transforming grid.

Photometric measurement is made on microphotometers (MF-2, MF-4, IFO-51, AMF-51, etc.). The diaphragm of a microphotometer is adjusted so that one mesh of a grid falls within the photometer's field of view. All the meshes embracing the working area are photometered. If the brightness coefficient ratio approach is used, pictures obtained in two regions of the spectrum are subjected to photometric measurement, namely 600-690 nm and 750-1100 nm. If, however, the brightness coefficient approach is used, only the picture obtained in the red band is used (600-690 nm).

Obtained as the result of photometric measurement, transparency values in each mesh (in relative units) are transferred to a geographical map of 1:1 000 000 scale which is broken up into squares corresponding to grid meshes.

When using information converted into digital form and recorded on magnetic tape, the data are put into the computer where geographical referencing is made. The results are output in the form of charts. The input data set is broken up into elements corresponding to squares with a side of 30-50 km in the field.

Some part of the squares is assumed as a reference for which brightness coefficients are determined on the ground-truth basis. To establish a reliable relationship between brightness coefficients of reference plots and magnitude of signal corresponding to the object's brightness, the number of squares must be at least 20. The total area of this quantity of reference plots 30 x 30 km in size makes up about 5 per cent of the area recommended to be investigated (500 x 700 km).

In choosing reference plots, the following principles should be observed:

- Plots must be as close to each other as possible. Maximum distance between plots is chosen so that the difference between sun altitudes at the extreme plots should not exceed 3^{o}. From this point of view, plots in a 100 x 500 km belt stretched along the width are advantageous;

- Brightness coefficients of reference plots in working spectral bands should cover the whole range in which brightness coefficients of the rest of squares over the investigated area may be found. A possible range of brightness coefficients over the investigated area is established from the results of the pilot aerial surveys.

Brightness coefficients are determined with the help of an aircraft at sun altitudes higher than 40°. Measurement at such altitudes allows the dependence of the desert's brightness coefficient on sun altitude to be neglected. The region of the spectral sensitivity of airborne photometers should be within the spectral bands in which the satellite survey is made.

Experience shows that in the period of maximum accumulation of vegetative mass when the yield of pasture vegetation is normally determined, the desert's brightness coefficients in the absence of precipitation vary so little in time that they may be held invariable during 5-7 days without large errors. Therefore, airborne measurements of brightness coefficients of reference plots need not be made the same day the space survey is made. This facilitates considerably the process of subsatellite calibration for in practice it is often difficult to combine aerial and satellite surveys simultaneously.

The above-mentioned circumstance allows several satellite pictures to be calibrated from the results of one survey. Since the size of reference plots is large, brightness coefficients are not determined over their entire area. Calculations demonstrate that the brightness coefficient of a desert square can be determined to a reasonable accuracy from the results of measurements over an area representing 6-8 per cent of the total square.

Thus, on a 100 x 500 km strip it is sufficient to lay four or five routes with the total length of 2-3 000 km.

With regard for the limitation in sun altitudes, such a job using the II-14 aircraft can be done in two or three days. It should be noted that the determination of the brightness coefficient over the whole area (500-700 km^2) would take about 15 days. Brightness coefficients of reference squares are determined as an average of the results of measurements along the routes involved in a given square. After brightness coefficients of reference desert plots have been determined the graph of the relationship between transparency values of the image of the reference desert plots and values of their brightness coefficients is plotted.

When using the brightness coefficient ratio approach the relationship is developed for two spectral ranges placed in the 600-690 nm and 750-1100 nm bands. If the brightness coefficient approach is used the relationship is developed only for the spectral range placed in the 600-690 nm band.

Figure 12 illustrates the relationship between brightness coefficients of reference plots in the Kyzylkum Desert in the 600-690 nm spectral band and the transparency of their imagery obtained in the 500-700 nm band. Based on such a relationship, brightness coefficients for the rest of the desert squares that were not involved in the reference strip are determined. For squares containing objects not related to pastures such as water surface, mountains, oases, etc., brightness coefficients are not determined. When using the brightness coefficient approach, the brightness coefficients of desert squares obtained lead to the same illuminance.

The accuracy of the determination of vegetative mass depends on the accuracy of determining the brightness coefficient of soil under plants. Therefore, for satellite data to be used, preparatory work on the determination of soil's brightness coefficients is necessary.

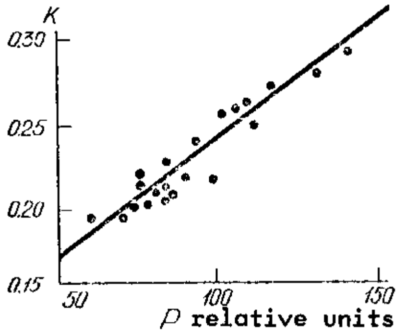


Figure 12 - The relationship between the transparency (P) of the image of reference strip sites and their brightness coefficients (K).

Because of the global coverage and low resolution of satellite surveys, there is no need to establish soil's brightness coefficients in small plots as is done in the case of ground-truth and airborne measurements. In this particular case, it is sufficient to restrict oneself to average brightness coefficients of basic soil massifs located in the photographed area. To that end, on the basis of a soil map, massifs with main soil types are singled out in desert pastures that are representative of the investigated area and for the massifs singled out, spectral brightness coefficients of soils are determined in working spectral bands.

Experience suggests that spectral brightness coefficients of soil on sandy pastures can be determined from an aircraft or helicopter. In this case, plots of sandy soil devoid of vegetation and representative of a given soil massif are selected. In order to make air-based selection of plots easier and to eliminate atmospheric effects on the results of measurements flight altitude should be 100-200 m.

For pastures on sierozems and takyr soils, most frequently, one cannot manage to select plots stretched enough, devoid of vegetation, and representative of each soil massif. Therefore, brightness coefficients of these soils are determined by ground-based techniques.

Helicopters and airplanes are also used to establish the limits of soil massifs in the field. Airborne and ground-truth measurements are made at sun altitudes higher than 30°.

From brightness coefficient values for desert squares, the yield of desert pasture vegetation in each square is determined by calibration curves (Figure 13a). In the determination of vegetative mass in squares, the calibration curve that corresponds to the soil brightness coefficient in a given square is used. The latter is determined from the location of the image of the square on a soil map.

When using the brightness coefficient ratio approach for each square, brightness coefficients in two spectral bands are initially determined and then their ratio is derived. The amount of vegetative mass is determined from the appropriate calibration curve plotted for the ratio of brightness coefficients (Figure 13b).

The obtained values of vegetative mass yields are put into corresponding squares on the 1:1 000 000 soil vegetation map (Figure 14).

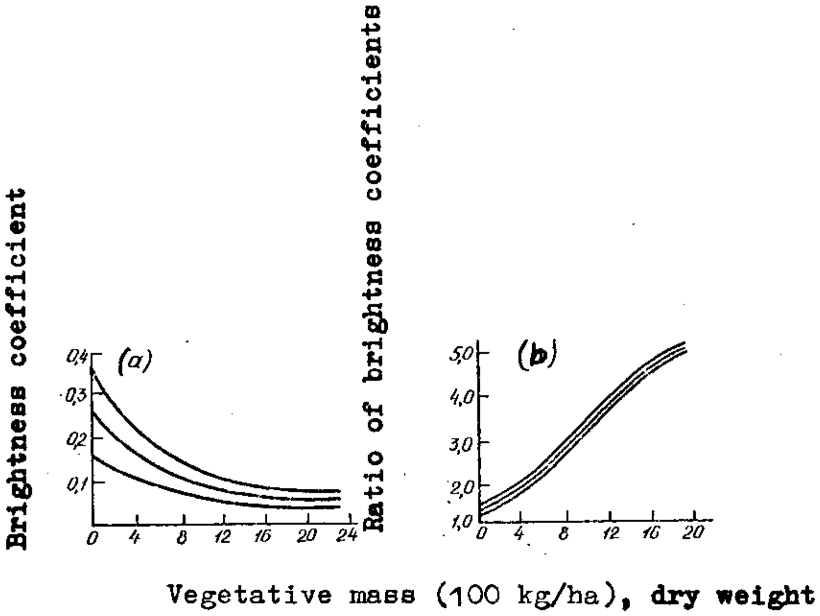
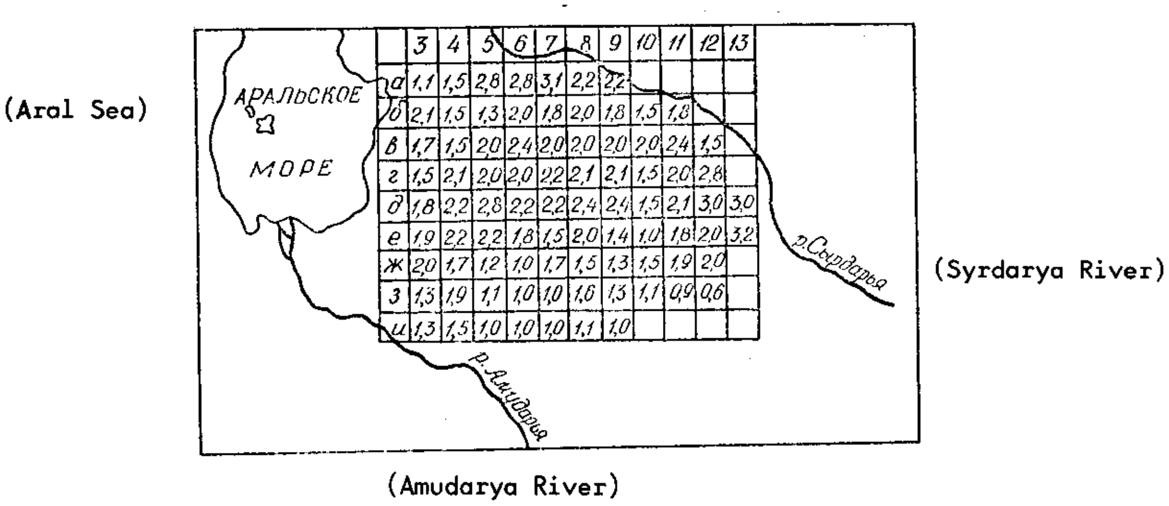


Figure 13 – Calibration curves for the determination of vegetative mass of pastures using (a) the brightness coefficient approach and (b) the brightness coefficient ratio approach.



	3	4	5	6	7	8	9	10	11	12	13
а	1,1	1,5	2,8	2,8	3,1	2,2	2,2				
б	2,1	1,5	1,3	2,0	1,8	2,0	1,8	1,5	1,8		
в	1,7	1,5	2,0	2,4	2,0	2,0	2,0	2,0	2,4	1,5	
г	1,5	2,1	2,0	2,0	2,2	2,1	2,1	1,5	2,0	2,8	
д	1,8	2,2	2,8	2,2	2,2	2,4	2,4	1,5	2,1	3,0	3,0
е	1,9	2,2	2,2	1,8	1,5	2,0	1,4	1,0	1,8	2,0	3,2
ж	2,0	1,7	1,2	1,0	1,7	1,5	1,3	1,5	1,9	2,0	
з	1,3	1,9	1,1	1,0	1,0	1,6	1,3	1,1	0,9	0,6	
и	1,3	1,5	1,0	1,0	1,0	1,1	1,0				

Figure 14 – The map of yield distribution in the Kyzylkum Desert, 7 May 1975.

The developed technique allows maps of the detailed distribution of desert pasture vegetation yields over an area of 30-50 million hectares to be obtained in two or three days. Comparison tests indicated that the difference between yield values obtained by the developed technique and the existing airborne technique was not beyond the 10 per cent limits.

7. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY AND MONITORING OF AGROMETEOROLOGICAL ASPECTS OF LAND MANAGEMENT IN ARID AND SEMI-ARID AREAS*

It has become possible, using processed climatic and agroclimatic data and information on water distribution and use, vegetation, cattle and wildlife, farm technology and population figures in conjunction with an assessment of social, economic and political conditions, to outline the overall ecological problems caused by desertification and to develop methods for preventing and combating desertification processes.

It should be stressed that an intensive, comprehensive study of the above-mentioned factors should be based on local information about the nature of, and interrelations between, the various resources in specific regions and countries.

The latter conclusion derives from the frequently observed impossibility of using general knowledge of specific local conditions, not because of the irrelevance of the study from which they derive, but usually because of the insufficiency or delay, especially of knowledge of local social, economic and political conditions.

Despite the insufficiency of the available basic information on arid and semi-arid ecosystems and desertification, substantial progress has nevertheless been made. Thus, from a first approximation based on numerous studies, it is possible to make a number of specific recommendations aimed at halting and in some cases reversing the desertification process. Below is a summary of the recommendations to be followed to achieve optimal use of meteorological, climatic and agrometeorological information and maximum control of farm production.

Measures to combat desertification

1. Optimal use of meteorological, climatic and agrometeorological information

(A) Development of a service to reduce and combat the influence of weather and climate in arid and semi-arid areas with desertification problems.

At national level, it is recommended to create or strengthen a committee composed of representatives of the scientific and technical organizations with a view to interpret, assess, implement and generate scientific and technological knowledge, through operational projects and associated investigations.

In order to increase the efficiency of meteorological, climatological and agrometeorological work, it is recommended to take the following steps:

(a) Data collection and processing

- Creation or expansion of an internal group to define tasks;
- Creation or expansion of a meteorological and agrometeorological station network to collect basic data;
- Creation or expansion of a data bank to permit collection, processing, analysis and assessment of basic data;
- Standardization of observing instruments for the sake of data compatibility.

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*Section prepared by M. Gabarotos (Argentina) and I. G. Gringof (USSR)

(b) Research

- Observation and continuous assessment of meteorological, climatological and agrometeorological conditions concerning the use of arid and semi-arid regions subject to desertification;
- Study of rare climatic events (droughts, strong wind, etc.), taking into account their probabilistic nature, and development of measures for their prediction and control;
- Production of climatic and agrometeorological maps, mathematical models, statistics and periodical probability tables;
- Research on weather modification;
- Testing of methods of calculating the water balance;
- Development of technical means for compiling weather forecasts which are typical for a given region;
- Use of satellite data;
- Study of micro-meteorological desertification processes;
- Improvement of climatic data and information from sources such as remote sensing, which are needed for improving land management in these areas;
- Agroclimatic zoning of arid and semi-arid areas subject to desertification;
- Study of the influence of meteorological factors on desertification as well as means to control desertification.

(c) Education and training at professional level

- Explanation of the conditions in arid areas and the causes of their formation and the occurrence of desertification; dissemination of this knowledge amongst the rural population;
- Creation of courses for specialists in the management of arid and semi-arid land and in desertification, both at technical and university level.

(d) National and inter-regional activities and co-operation

- Exchange of information between organizations concerned with arid and semi-arid areas subject to desertification;
- Participation in regional and international meetings on the special problems of these regions;

- Co-operation between national and inter-regional organizations concerned with the observation of meteorological, climatic, agrometeorological and agricultural conditions in arid areas, in order to agree on and co-ordinate joint action under the general plan to combat desertification.

2. Maximum use of modern technology and measurements

(A) Development of programmes for surface and upper-air observations and of aerial and satellite photography to produce data on climate, soils, water distribution, vegetation, animals and centres of population, in order to make an assessment of the biomass, virgin forest, rangelands and cattle, dust-cloud movements, agglomorations of cattle and people, the state of watering places, erosion processes, droughts, etc.

(B) Development of computer programmes for data collection, processing and analysis in order to improve our knowledge of desertification processes and to have a departure point for a continuous programme of ecological monitoring and control of arid areas, in particular those affected by desertification.

3. Maximum control of farm production

(A) Overgrazing

(a) Control and improvement of rangelands

- Determination of climatic conditions: type and state of soils and vegetation; development stages of rangeland and the critical grazing stage; existing grazing system; reserves of forrage, water and watering places; grazing rate and field receptance; further studies on desertification for the purposes of land management and improvement;

- Creation of a permanent reserve of hay to compensate for natural fodder shortages during droughts; use of second sowings (which usually come from natural dispersal of the seeds);

- Cultivation of high-yield fodder crops suitable for arid conditions using special sowing techniques, e.g. in strips with added fertilizers to increase productivity and wind-breaks;

- Destruction of strictly limited number of shrubs and thorn bushes to eliminate their competition with the pastureland for moisture and nutrients; the destruction should not be complete, since because of their drought-resistance and trampling around them by animals they are capable of greatly stablizing the soil, which in turn improves the general state of the pastureland;

- Installation of artificial watering places adapted to the traditional nomadic cattle grazing in order to minimize potential degradation of the soil and pastureland in areas of overgrazing and trampling, especially around the natural watering places;

- Rotational use of pastureland in order to rest and renew the fodder grasses and enable them to grow, particularly in the moist periods when they develop well; in other words, measures preventing rangeland exhaustion;

- Reduction of the number of grazing animals, depending on the number which can be supported by a given area of pastureland, remembering that it is easier to renew cattle than to renew the soil and pastureland after their disappearance or degradation.

(B) Salinization

(a) Control and land improvement

- If the soil is not saline, check that the irrigation water does not contain salts, especially those of sodium, and irrigate the land frequently and in small doses in order to slow down evaporation; it is particularly dangerous to increase the concentration of dissolved salts in the rooting zone and raise the level of the groundwater if the water has a high salt content;

- Saline, well-drained earth can be used if a natural or artificial drainage system is set up and frequent, intensive flushing is done with salt-free water;

- It should be borne in mind that, during irrigation of saline and saline-alkaline soils, an increase in alkalinity may occur. In order to avoid this, the soil should first be tilled with gypsum or sulphur which converts the harmful bicarbonates and carbonates of sodium into the neutral sodium sulphate which can be removed by wash-out;

- In areas which are subject to salinization, crops should be chosen or new strains of grasses should be made which are able to withstand salt in the soil, e.g. lucerne, sorghum, barley and clover.

(C) Tree felling

(a) Control policy

Study of standard felling rates and the means for preserving or renewing the forest (bush) cover in order to develop or improve the control system.

(D) Litter burning in rangelands

(a) Control system

Experiments on litter-burning in pastureland in order to obtain information on its effects on the vegetation itself, the soil, animals and socio-economic conditions of the region and thus determine a system for controlling or improving it.

(E) Erosion and dune formation

(a) Management and improvement of land subject to wind erosion

- Study of the state of the soils in order to improve their wind-resistance; creation of soil-protection strips or continuous plant cover; tilling of the land with appropriate means and methods using inert materials, e.g. by leaving the stubble, thus reducing wind erosion;

- Study of the effect of wind (direction, speed) and precipitation (distribution, intensity, duration, frequency) on erosion and the conservation of soil moisture;

- Installation of wind-breaks or planting of trees in strips or at a certain distance from each other at right angles to the prevailing wind direction;

- Crop rotation in order to keep the soil almost always covered with vegetation and thus prevent removal by the wind;

- Development of methods for tilling the soil which leave it in compacted lumps thus avoiding the use of an inverter which leaves the soil bare;

- Stabilization of soil subject to erosion immediately after sowing, e.g. by using a non-plant mulch (cellulose tissue) or organic and non-organic liquids which form an erosion-resistant film (aqueous emulsion of petroleum-based resins);

- Limitation of grazing and overgrazing;

- Organization of plowing and sowing only at favourable times;

- Felling of forests only as an exception and under strict control;

- Litter-burning as an exception and under strict control.

(b) Management and improvement of land subject to water erosion

- Proper consideration of factors influencing this type of erosion, (e.g. driving rain, relief, soils, vegetation) and methods for combating wind erosion;

- Ploughing in a direction perpendicular to slopes which are subject to erosion;

- Planting of crops in strips perpendicular to the slope, with protected edges and terraces.

(c) Management and improvement of land with moving dunes (barkhans)

- Studies of dunes in order to clarify knowledge of their formation, topography, stratification and the physico-chemical composition of the sands;

- Development of sand stabilization, e.g. with protective planks or dry bushes; soil stabilization, e.g. by planting species which are suitable for these conditions with an extensive root system at the surface and flexible, fairly thin stalks in order that they do not carry much sand above them such as Amnophila arenaria, and which are also useful. Such examples are: Acacia cyanophylla, Eucaliptus camaldulensis, Pinus pinaster, Haloxyn aphyllum, Haloxylon persicum, Salsola richteri, Ammodendron conollyi, Aristida karelini, Aristida pennata; strains of the species Artemisia, Kochia, Aelenia; semi-shrubs of the type Astragalus, Mausolea, etc.

(d) Monitoring and improvement of socio-economic, political and cultural factors

- Location of arid and semi-arid areas with desertification problems; determination within them of suitable areas (from the socio-economic, political and cultural point of view) for creating or improving an infrastructure to enable the local population to use the resources more fully and rationally;

- Population studies in arid regions in order to make a comprehensive analysis of socio-economic, political and cultural factors in particular situations and determine the role of these factors for each region;

- Encouragement of direct participation by the population of the studied areas in development programmes and implementation of measures adopted;

- Gradual narrowing of the differences between scientific and technical progress, on the one hand, and ignorance of it, on the other, in order to understand and use scientific and technical achievements effectively;

- Limitation of overpopulation in relation to the potential resources and existing technology by repopulating areas with many resources or areas which are generally unused;

- Effective approach towards the purchase of land, water and technology by providing credit with reasonable interest and repayment deadlines, depending on the socio-legal standards and regulations adopted in the particular country;

- Promotion of the construction of housing and work buildings which are suitable from the human and climatic points of view;

- Provision of health care and education of families in arid regions;

- Use of the experience of more advanced countries (e.g. the U.S.S.R.) which have achieved considerable success in the rational use of natural resources in arid and semi-arid areas and which are solving more fully the socio-economic problems of the populations in these areas.

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