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D.O. Bergin

Report on

**SAND DUNE STABILIZATION
IN ISRAEL**

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREFACE

The investigations reported here were submitted to the FAO/DANIDA Inter-regional Training Centre on Heathland and Sand Dune Afforestation (August-September 1973) in response to a call for current information on the topic of dune stabilization. These investigations, which were not presented or discussed at the Centre, are presented separately from the Centre Proceedings itself, which is to appear as another publication.

The FAO Forestry Department (Forest Conservation and Wildlife Branch) gratefully acknowledges the support of the Danish International Development Agency (DANIDA) which generously supported the Centre as well as the ensuing publications. We are also grateful to Dr. Tsuriehl of the Ministry of Agriculture, State of Israel, for the preparation of these manuscripts.

Dr. Tsuriehl is Chairman of the International Cooperation Group on Sand Dune Reclamation (ICSR), a group of independent scientists, on whose behalf the material was presented to FAO and DANIDA.

PART I.

A REPORT ON APPLIED RESEARCH AND FIELD APPLICATIONS IN DUNE AREAS

1. Introduction

Since 1948, continuous scientific research has been in progress, including field trials and laboratory work. In order to carry out stabilization works of extreme urgency, it was not always possible to wait for the final results of the research. This way, operations in the first year of the 3rd decade have not always been based upon the results of the research, but also on traditional methods used beforehand, and upon intuition. On the other hand, these large-scale operations added a great deal of information to the technical knowledge and they supplied important data about the successes and failures obtained in the field.

As the State of Israel includes areas of varied climatic conditions, it has been possible to compare the results as reactions to these different conditions, especially those of the more humid regions of the North with those of the desert regions in the South (see Appendix: Climatic Data).

2. Sand Dune Formation in Israel

Almost the whole of the Israel coast South of Tel Aviv — Jaffa is fringed by sand dunes gaining an inland depth of 5 km and more (up to 10 km) at many places. North of Tel Aviv — Jaffa the dune belt is more often interrupted and, with the exception of the Hadera-Caesarea region, it is much narrower.

It is assumed that these dunes have originated from one of the following three sources:

- a) the southern and central coastal belt, from Rafa in the South to Acre in the North, was transported to Israel by the Nile, carrying constantly large quantities of sand from the desert bordering both sides of the River Nile, from Central Africa to Egypt, and ejecting it into the Mediterranean. Sea currents bring this sand to the Israel coast and forces of the wind cause its deposition;
- b) the northern coastal belt, from Acre to Rosh Harikrah, on the Lebanese border, seems to be the product of local weathering of calcareous stones. The sand particles are freed by constant decomposition, forming massive areas of sand dunes;
- c) the Negev dune sand, south of Beer Sheva, originated from the Sinai desert and accumulated during wind storms.

Accumulations of larger sand dune areas are to be found in Emek Zevulun (1,300 ha), near Caesarea (3,000 ha), between Rishon Le Zion and Ashkelon (19,390 ha) and in the Negev, south of Beer Sheva (114,000 ha). The total surface of inland and sea-shore dunes, with the exception of the Sinai Peninsula, is 140,000 ha.

3. Practical Problems

Sand movement causes severe damage by inundating traffic lines, agricultural land, industrial centres and even complete settlements. In order to protect these objects, it is necessary to avoid aeolian sand movement. The traditional methods include:

- a) stabilization by vegetation;
- b) engineering measures (fences, artificial barriers, "foredunes" and diversion trenches);
- c) mulching the surface of the sand.

In order to choose the right method, the following points have to be brought into consideration:

- a) since the use of vegetation is conditioned by rainfall, planting work is possible only at the beginning of the rainy season, which is very short. Large-scale operations need a great deal of manpower, especially when mechanical methods of planting are used. When a shortage of manpower occurs, it becomes extremely difficult to mobilize enough labour for this work;
- b) in desert areas where artificial irrigation is impossible, it may be difficult to introduce vegetation at all. In these cases, technical means and mulching may be the sole solution for avoiding sand dune movement. But these measures, in the long run, may not be efficient enough. They often require repetition of the procedure after two or three years;
- c) there are urgent cases when operations have to be executed in the middle of the dry season, not so much because of massive sand movement (as wind velocities in this period are relatively low), but because the blowing of fine sand particles (dust) may cause severe damage to machines in factories located in the sand dune areas. Special methods have to be found to cope with the problem of how to carry out operations during the dry season;
- d) the old method of mulching the surface of the ground by hay, straw or dead twigs has become unfeasible, as a consequence of lack of manpower and the very high cost of the distribution of such material by hand (see: Mulching).

4. Stabilization by Vegetation

The choice of plant species has been guided by the necessity to find ways of direct mechanical sowing, instead of hand-planting. Plant species have been selected from nature with the help of conventional ecological and syn-ecological systems (Brown, 1954).

The challenge was to obtain seed material suitable for sowing directly into shifting sand dunes. Among these species, the following ones have been successful:

Ammophila arenaria
Agropyrum junceum
Lotus creticus
Retama roetam
Polygonum equisetiforme
Mesembryanthemum acinacifolium

The method of direct sowing enabled also the use of a mixture of seeds from various perennial plants (Tsuriehl, 1966), together with annuals, each sown in alternate rows at 50 cm between rows, or in severe cases as little as 30 cm. As an annual plant, an Australian

ecotype of rye, Secale cerealis is quite useful. The rye germinates and grows rapidly, establishing the area at the very beginning of the operation. At the same time it protects the slower growing perennials. In the second year, no competition occurs between the annual and the perennials. However, the stem, the only residue of the dead annual, still protects the perennials by serving as a wind-break.

The ecological study of the spontaneous sand dune vegetation has a dual purpose: it may be indicative for revealing characteristic conditions in nature, such as the depth of water table, depth of the sand layer, rate of sand movement, as well as climatic data on wind velocities and wind directions (Tsurieil, 1959, 1960, 1963). The indicative value of the sand dune vegetation is particularly important in areas where meteorological and soil data are not easily available, or their collection is difficult. On the other hand, the behaviour characteristics of the vegetation, especially its sand accumulative power, wind-breaking capacity, the rapidity of root growth, resistance against wind and drought, resistance against sand inundation and against sea water or brackish water inundation, are all important for choosing the most effective species for sand dune stabilization.

It may be advisable to choose plant material from the same area in which the stabilization work has been executed, as this approach guarantees the best establishment and best ecosis (i.e. plant adjustment) of the introduced vegetation.

Among the above-mentioned species, Ammophila arenaria (European Beach Grass) is undoubtedly the most reliable one. However, the adult plant needs the influx of fresh sand. If not, its survival becomes doubtful. This problem is now under investigation. It seems that the lack of certain nutrients, and especially of certain micro-elements, causes the degeneration phenomena of this grass.

The direct sowing of Ammophila arenaria, provided the surface of the sand is protected by a chemical crust (see: Mulching), has led to very satisfactory results, and has lowered the cost of manpower from US\$ 2,000 to US\$ 200 per hectare (preliminary fertilization included). On steep slopes, one-year-old seedlings in nylon bags have been planted to a depth of two feet, the hole being dug mechanically. Even under the most severe conditions, as in the Gaza Strip and in the Sinai Peninsula, this plant has been established quite successfully. It produces an abundance of seeds when grown near the sea. The seed production seems to be linked to a sub-tropical climate. In spite of this fact the plant, which is global in distribution, does not produce seeds in either cold or temperate zones or in the tropics. For this reason, considerable quantities of the seed are sent every year from Israel to other countries.

Recently "mother plantations" of Ammophila have been planted in sites where the optimal conditions of seed production can be investigated.

Another plant of the above list deserving special attention is Lotus creticus, a legume possessing active nodules which enrich the sand with nitrogen. This fact is especially important in areas where the objective is not only to fix the sand, but also to turn it into fertile land having agricultural value.

A plant which has not yet been used on a large scale is Zygophyllum album, a species resistant to high salinity. It has been collected from its natural environment, the lagoons in the Mediterranean, where it occurs spontaneously on the banks of the lagoons. Practical ways of reproducing it have been found. This plant shows promise for use in sand dunes where saline irrigation is possible.

Heterotheca subaxillaris, introduced from Texas, U.S.A., has shown better response to the conditions in Israel than to those in its homeland. Various plants have been introduced from Australia, South Africa, U.S.A., India, Japan and Russia (Tsurieil, 1971).

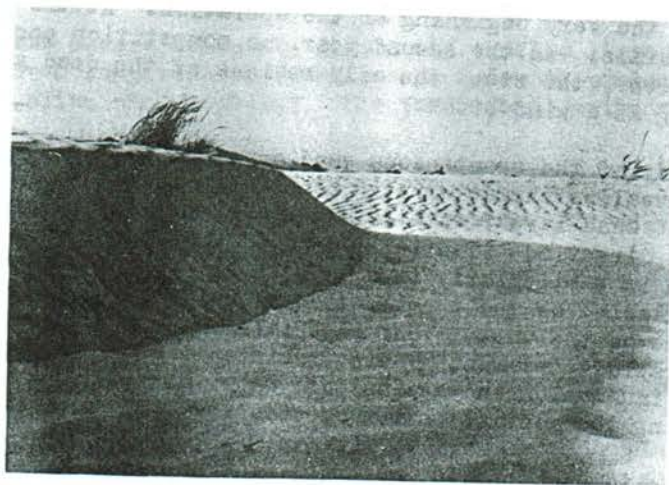


Fig. 1 - Sand dunes before treatment.



Fig. 2 - First stage of the germination of *Ammophila arenaria*, sown directly onto the drifting dunes.

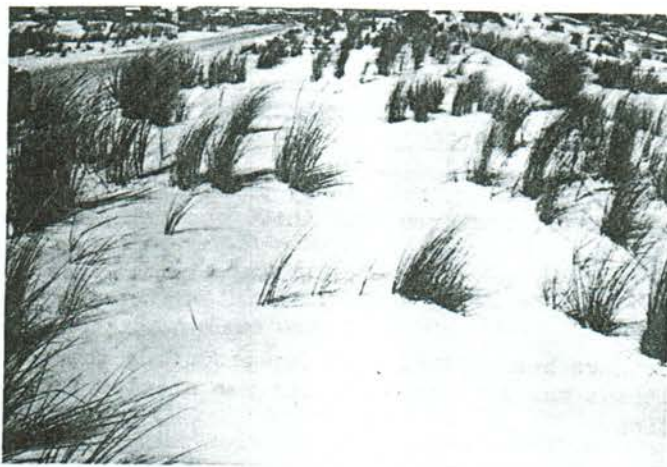


Fig. 3 - Protection of a road from shifting sand by use of Ammophila arenaria (2 years of age).



Fig. 4 - Another view of the Ammophila arenaria growth two years after direct seeding onto a drifting dune area.

Other plants, which cannot be sown, have been transplanted in nylon bags:

Acacia cyanophylla
Artemisia monosperma
Pennisetum dichotomum
Calligonum comosum
Saccharum biflorum aegyptiaceum

These plants have led to satisfactory results by planting but not by sowing, as their germination requires higher temperatures than those occurring in the rainy season.

The mechanical filling of nylon bags with soil mixtures in the nursery is now under investigation.

Special nurseries have been established for producing the necessary plant material adapted to local conditions and for investigating new species from abroad, as well as from the indigenous vegetation.

5. Engineering Methods

5.1 Fences

The slat-type fencing has been replaced by plastic fabrics of 48 percent porosity. Fences have been erected according to the results obtained by the research of Savage and Woodhouse (Savage and Woodhouse, 1968). This publication also includes interesting details on how to erect "foredunes" and some of these systems described have been successfully applied in Israel.

The fences accumulate huge quantities of sand in a very short time. It has been very important to fix at least the crest of the "foredune" by planting, mulching or oiling (Kerr and Nigra, 1952). Such foredunes, erected by bulldozers at strategic points along new highways in the desert and fixed by oil or other chemicals, may be an effective solution for the protection of highways in those areas where planting is impossible. Aerial photo studies may reveal the location of these strategic points (see: Use of Aerial Photography).

5.2 Diversion trenches

The idea of Kerr and Nigra (1952) to open trenches with bulldozers, latitudinally and longitudinally, has been tested under Israeli conditions and found to be an effective method of diverting wind into desirable directions. This method, of course, needs preparatory study of the regional sand-movement which can be obtained by aerial photographic analysis.

5.3 Mulching

Mulching with straw or twigs has been totally abandoned and replaced by chemicals. The chemicals below have been tested in field trials. The exact chemical formulations of the patented products are unknown, except to the manufacturers; however, there are various bituminous, plastic or polymeric emulsions:

Bituminous emulsions
Curasol
Huls 801
Unisol 91
Coharex
Rohagit
Polymeric emulsion of Askar (Emulsol)
Crude Oil.

Numerous laboratory tests and statistical field experiments with all these products have led to the following preliminary conclusions:

- a) Each product possesses specific characteristics;
- b) these characteristics, in order to assure full success, have to be adapted to the particular conditions of the plot (Tsurieil, 1971);
- c) often the price of the product and the cost of transport may be decisive in selecting one in preference to another;
- d) for this reason, when large-scale operations have to be carried out under varying soil and climatic conditions, it is advisable to have a stock of several of the manufactured products and to use each of them according to the specific conditions of individual sites;
- e) products manufactured in the home-country are, of course, advantageous by saving transport costs. But since most of the products have to be diluted by water, it is often advisable to buy the extract, or even part of it, from abroad, which considerably lowers the cost of transport and thus the price of the whole procedure;
- f) the following values have been used as a standard formula for application per unit of surface and rate of dilution by water:

700 kg of "Emulsol" per ha, diluted in 3,500 litres of water. This formula has proved satisfactory for levelled areas and slight slopes. The rate has to be increased to 1,000 kg "Emulsol" per ha diluted in 5,000 litres of water for steep slopes, i.e. exceeding 5 percent. (Note that each product has its own formulation prescription).

In order to check the reliability of the crust, the following experiment was carried out:

In the middle of the dry season (July 1961) sand dunes of six ha were sown by sand-binding plants, fertilized and sprayed by polymeric emulsions, without artificial irrigation. After the first rainfall, November 1961, excellent germination occurred.

This test proved that the crust conserved the surface of the sand, maintained the exact depth of the seed and avoided topographical changes of the sand. Following these results, large-scale operations were conducted with similar success. This kind of summer operation solves the problem of urgent stabilization in the dry season. It was surprising that the tractor sowing in totally dry sand carried out its work with less difficulties than under winter conditions. Also, all other manipulations of the work (sowing, spraying, fertilizing) have been more favourably done than in winter, when wind storms often disturb the work in the field.

As a whole, the chemicals have proved to be an efficient and relatively cheap measure for stabilization. In localities where the use of vegetation is problematic because of lack of rainfall, the chemicals may be used as an exclusive measure for stabilization, as in the case of a large-scale operation for the protection of the railway line in the Negev where sandy slopes were menacing the line. This work was done without any use of vegetation. After six years, the crust is still intact and prevents erosion of the slopes.

6. The Use of Municipal Refuse

Enormous amounts of garbage are produced by large towns throughout the world, and the disposal of this material becomes more and more a severe environmental problem. Since 1966, experiments have been made in Israel to test the possibility whether sand dunes may absorb these materials without any previous composting for dune stabilization purposes and for

agricultural use. The garbage has been incorporated into the sand at a depth of two feet, with various plant species being grown above the garbage. These experiments led to the following results:

- a) the garbage served as an excellent fixative of the loose sand;
- b) among the twenty tested species, five species were able to grow in fresh garbage. One of them produced green fodder consumed by cattle and sheep at a rate of 20 tons per hectare per year. This fodder plant, introduced from the Negev, is called Pennisetum dichotomum;
- c) the best rate of garbage per hectare seems to be 2,000 m³/ha. However, plants also survived and thrived above garbage applied at a rate of 5,000 m³/ha;
- d) composting took place after eight months instead of the three weeks in the compost factory;
- e) no infectious microbes of danger to man or animal occurred when the garbage was covered by at least a one-foot layer of sand.

The following twenty species have been tested, and the first five were successful. Numbers 6 and 7 have proved fairly satisfactory:

- | | |
|---------------------------------------|-------------------------------------|
| 1. <u>Pennisetum dichotomum</u> (S) | 11. <u>Eucalyptus rostrata</u> |
| 2. <u>Lotus creticus</u> (S) | 12. <u>Ammophila arenaria</u> |
| 3. <u>Artemisia monosperma</u> (S) | 13. <u>Agropyrum junceum</u> |
| 4. <u>Oenothera drummondii</u> (S) | 14. <u>Pancratium maritimum</u> |
| 5. <u>Polygonum equisetiforme</u> (S) | 15. <u>Galenia secunda</u> |
| 6. <u>Acacia cyanophylla</u> (FS) | 16. <u>Zygophyllum album</u> |
| 7. <u>Tamarix articulata</u> (FS) | 17. <u>Heterotheca subaxillaris</u> |
| 8. <u>Calligonum equisetiforme</u> | 18. <u>Atriplex lentiformis</u> |
| 9. <u>Retama roetam</u> | 19. <u>Atriplex halimus</u> |
| 10. <u>Cassia sturtii</u> | 20. <u>Acacia sophorae</u> |

S=successful; FS=fairly satisfactory; remainder failed.

7. The Use of Aerial Photography for Dune Stabilization Planning

For planning of sand dune stabilization operations it is advisable to first collect aero-dynamic data of the whole region involved, in order to envisage or predict the possible movements of the sand dunes, their topographical changes and to know more about the localities where there are critical points of menace to the object to be protected. Such geo-morphological studies, it is true, have been done by many research workers, especially by Bagnold (1941). But most of this research has been executed in deserts where the rate of sand movement of various dune types, such as Barchans, Seifs, have been mathematically determined. In areas with partial plant cover and higher air humidity and soil moisture, however - not real desert areas - the laws of sand movement have been studied less. For this reason, it is advisable to study sand movement via aerial photography and to add this information to the knowledge about sand dune movement in the desert.

In Israel, aerial photos from the last twenty-five years have been analysed and compared with the help of an autograph, a machine which corrects differences, bringing all scales of the photo to precisely the same size (Stoch and Finkle, 1973). This assessment has been done for sand dunes of 1,000 ha which are situated a hundred kilometers south of Haifa. The analysis of the photos revealed interesting phenomena on the mechanism of sand dune movement, its direction, and changes in shape and height of the dunes. These data enabled us to evaluate the rate of danger and the points where protection work is most urgent. Such photogrammetric analyses may therefore be of important value and serve as a basic guide for any dune stabilization planning.

The Use of Machines Adapted to Dune Stabilization

The following machines have been built for stabilization purposes:

- a) a sowing machine for direct sowing of sand dunes;
- b) a motorized digging machine for excavating holes for planting seedlings in nylon bags;
- c) threshing machines for sand-binding plants;
- d) a motorized sprayer for distributing liquid chemicals for superficial mulching.

Furthermore, a motorized machine for collecting seeds in nature has been invented by Mr. Petcoff, California, and has been sent to Israel for facilitating this work. The designs of these various machines are available from the I.C.S.R. by request and arrangement.

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10. Appendix to Part I.

10.1 Physical and chemical properties of the sand

Table 1 gives details of the physical and chemical properties of the sand samples taken from the coastal sand dunes between Haifa and Acre. This table indicates that the content of organic matter is very low, while porosity is rather high (42 percent). The field water capacity is 4 percent.

Table 1

Physical and chemical properties in percent (except for pH)

Hygroscopicity	Porosity	Water Capacity (% of water)	Field Capacity	
0.1	42	27	4	
Organic matter	Nitrogen	Chlorines	Soluble Salts	pH
0.03 - 0.07	0.004-0.01	0.003-0.01	0.05	8.5

Table 2 gives details of size in diameter of coarse and fine sand particles and the amount of calcium carbonate in a number of places along the coastal sand dunes. This table shows that the diameter of the sand particles may vary considerably from place to place, but the majority of the coastal sand dune areas consist of fine sand (particles of less than 0.2 mm diameter).

Table 2

Percentage of coarse sand, fine sand and CaCO_3 for various sites along the coast (Zohari and Fahn, 1952)

Locality	Coarse sand above 0.2 mm	Fine sand below 0.2 mm	CaCO_3
Gaza	2.7	97.3	2.0
Herzilia	39.8	60.2	3.9
Kyriat Hayim	0.16	99.84	9.8
Mishmar Hayam (Acre)	0.36	99.64	11.2
Shave Zion	99.7	0.3	78.0
Kyriat Yam	3.3	96.7	9.7

10.2 Climate

On the basis of its geographical position, Israel belongs to the sub-tropical zone, but on the coast, in particular, as well as in the highlands, the climate is decidedly of a Mediterranean type. The Negev and the Jordan depressions display arid conditions. The most striking feature of the Israel climate is the occurrence of a well marked season of

winter rains. Two entirely different climatic seasons alternate with one another, in that five of the summer months are nearly rainless and three are completely devoid of rain.

10.3 Rainfall

Rainfall data for a number of localities are shown in Table 3. The data illustrate that rainfall obviously diminishes from north to south, with frequent variations of the monthly mean, the most rainy months being December and January.

Table 3

Mean monthly and annual rainfall in mm (reduced to period 1901-1930)

Station	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual
Acre	2.6	29.4	86.1	161.8	175.7	114.4	41.4	33.3	7.3	652
Tel Aviv	1.8	18.8	65.9	133.6	144.0	91.9	41.1	15.8	2.1	515
Ashkelon	0.1	15.0	63.0	108.4	118.0	71.6	36.7	9.5	0.7	423
Beersheba	0	5.0	26.4	56.1	52.0	40.6	31.3	13.2	2.4	227

10.4 Wind

Wind data for three localities are given in Table 4. In this table, frequency of all strong winds is registered in percent of all winds which blew during observation time. The figures illustrate that strong winds of eight on the Beaufort scale (67.7 km/hr) and above occur in January, February, March and December, and their frequency is low (between 2 and 90 percent). East and south-east winds occur at approximately the same rate as west and north-west winds of eight Beaufort.

Table 4

Frequency of winds above 8 on the Beaufort scale (67.7 km/h) expressed in percent of all available winds

Month	Hour	Acre				Tel Aviv				Gaza			
		SW	W	E	SE	NW	W	SW	S	NW	W	SW	N
January	6.00					4				2			2
	14.00			2	2	2	6						
	20.00			2	2			6	2				
February	6.00						2	6				4	
	14.00					2	4	2		4	4		
	20.00										9		
March	6.00						4						
	14.00										2	2	
	20.00										2	2	
December	20.00		4	4	4	4							

Further observations on winds by the meteorological service through eight consecutive years have shown that 91 percent of all winds that blow along the seashore are of a velocity below 24 km/h. Strong winds occur often, but they are of a short duration. These winds cause the movement of loose sand on a large scale.

10.5 Temperatures

Temperature data as average monthly minimum and maximum values calculated from periods of 15 to 20 years are given in Tables 5 and 6. These tables illustrate the following points:

- a) the lowest minimum temperatures occur during January and February, with no significant differences between the northern and southern parts of the country;
- b) maximum temperatures above 30°C occur from March to November;
- c) the rainy months are December and January and the December minimum temperatures are higher than the lowest minimum temperatures in January, indicating that the best time for sowing and planting is in December, when the appropriate soil moisture and temperatures occur together.

Table 5
Average monthly minimum temperatures (°C)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acre	4.1	4.5	4.8	6.9	10.4	14.8	18.3	19.4	16.5	13.0	8.9	5.4
Tel Aviv	3.0	3.6	4.2	5.9	9.8	13.7	17.1	17.9	15.3	11.3	7.7	4.9
Gaza	4.3	4.7	5.1	7.4	11.3	15.0	17.8	18.7	16.7	13.8	9.3	5.4

Table 6
Average monthly maximum temperatures (°C)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acre	22.3	24.7	29.4	34.1	36.2	33.6	32.0	32.3	33.0	35.7	31.2	25.2
Tel Aviv	23.4	25.1	30.3	32.4	32.9	31.4	31.2	31.8	32.0	33.3	29.8	25.5
Gaza	24.1	27.1	32.2	36.0	38.6	36.1	33.5	33.8	34.4	34.1	31.4	26.8

PART II.

A REPORT ON THE EFFECTIVENESS OF THE "CURASOL" (TM) PRODUCT FOR DUNE STABILIZATION ^{1/}

1. Background

The "Curasol" (TM) product has been tested in Germany and Holland and has come into use in several countries. However, it has been necessary to test it again under the specific conditions of Israel. Factors considered have been the physical and chemical characteristics of the sand particles, climatic conditions (especially wind velocities, directions and frequencies) and also different percentages of dust and sand particles in the air. Rainfall rates, the long dry summer period and the high sun-radiation intensity also were considered. These are all factors which are able to deteriorate the spray product, resulting in a crushing of the chemical film. Another aggravating factor is the high soil temperatures during the summer season, in particular that of the upper layer of sand. All these factors necessitated a special investigation for determining the response, behaviour and effectiveness of the product for sand dune stabilization purposes.

2. Objectives

The objectives of the investigations were:

- a) to examine the effectiveness of the product in different environments, especially in protected and in open sand dune areas;
- b) to test the material in connection with certain sand binding species, in order to determine the response of these species to the crust created by the spray product. To test the material in relation to plants planted in nylon bags and with plants sown into sand by tractor-drawn sowing machines. To test any possible damage caused to the plant by the spray.

At this stage it was not the objective to test different rates of dissolution of the product in water.

3. Description of the environmental conditions of the experimental areas

Experiments were done in two different locales: at the Experiment Station on Sand Drift Control near Haifa (1,000 metres from the seashore), and in an open area of wild shifting sand dunes near Ashdod, 500 metres from the seashore. The Experiment Station near Haifa is in a protected area on level ground (Figures 5 and 6).

Characteristics of the sand at the Haifa site are shown in Table 1 (Part I). Sand particle sizes and carbonate content also are given in Table 2 (Part I) for the Kiryat Yam site (near Haifa).

Wind data are given in the diagram of Figure 7. The frequency of winds above 3.3 Beaufort are given as a percentage of all the high velocity winds registered during eight consecutive years, for December, January and February exclusively (in all other months the meteorological wind readings show lower velocities than 3.3).

^{1/} Mention of any product by name does not constitute an endorsement or opinion by FAO. All opinions and conclusions regarding products are solely those of the author.

Figure 7 demonstrates the following:

- in the Akko region, the SE wind is the prevailing wind, representing approximately 40 percent of all registered wind velocities. The SW wind (21.8 percent) is the next most common;
- in the Tel Aviv region, the prevailing wind is from SW (30 percent), followed by the west wind (20.6 percent).

It has to be emphasized that all the data mentioned above are based on three readings per day. They do not include the sudden gusts which may have caused considerable sand dune movement.

Rainfall and temperature data for the two sites are given in Tables 7, 8 and 9.

Rainfall

Table 7

Mean monthly and annual rainfall in mm

Station	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual
Akko	2.6	29.4	86.1	161.8	175.7	114.4	41.4	33.3	7.3	652
Tel Aviv	1.8	18.8	65.9	133.6	144.0	91.9	41.1	15.8	2.1	515

Note: No rainfall during June, July and August.

Temperatures

Temperature data as average monthly minimum and maximum values calculated from periods of 15 to 20 years, are given in Tables 8 and 9.

Table 8

Average monthly minimum temperature (°C)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Akko	4.1	4.5	4.8	6.9	10.4	14.8	18.3	19.4	16.5	13.0	8.9	5.4
Tel Aviv	3.0	3.6	4.2	5.9	9.8	13.7	17.1	17.9	15.3	11.3	7.7	4.9

Table 9

Average monthly maximum temperature (°C)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Akko	22.3	24.7	29.4	34.1	36.2	33.6	32.0	32.3	33.0	35.7	31.2	25.2
Tel Aviv	23.4	25.1	30.3	32.4	32.9	31.4	31.2	31.8	32.0	33.3	29.8	25.5

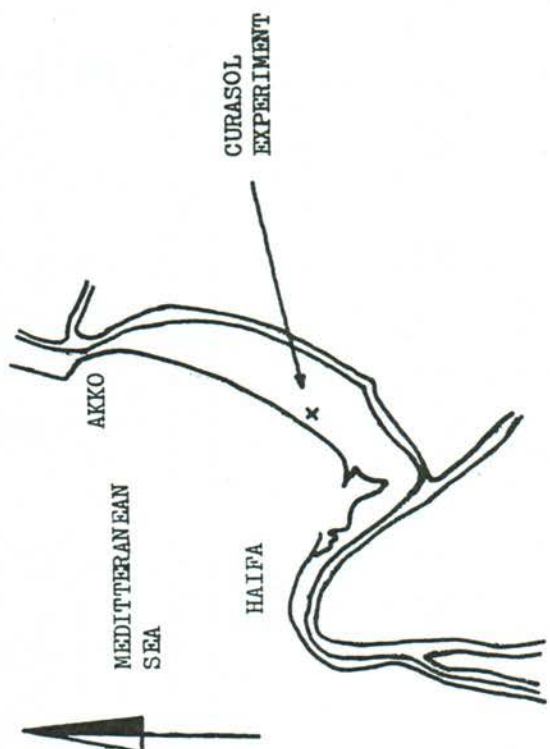


Figure 6: LOCALITY OF THE EXPERIMENT
STATION ON SAND DRIFT
CONTROL NEAR HAIFA (the
more protected site)

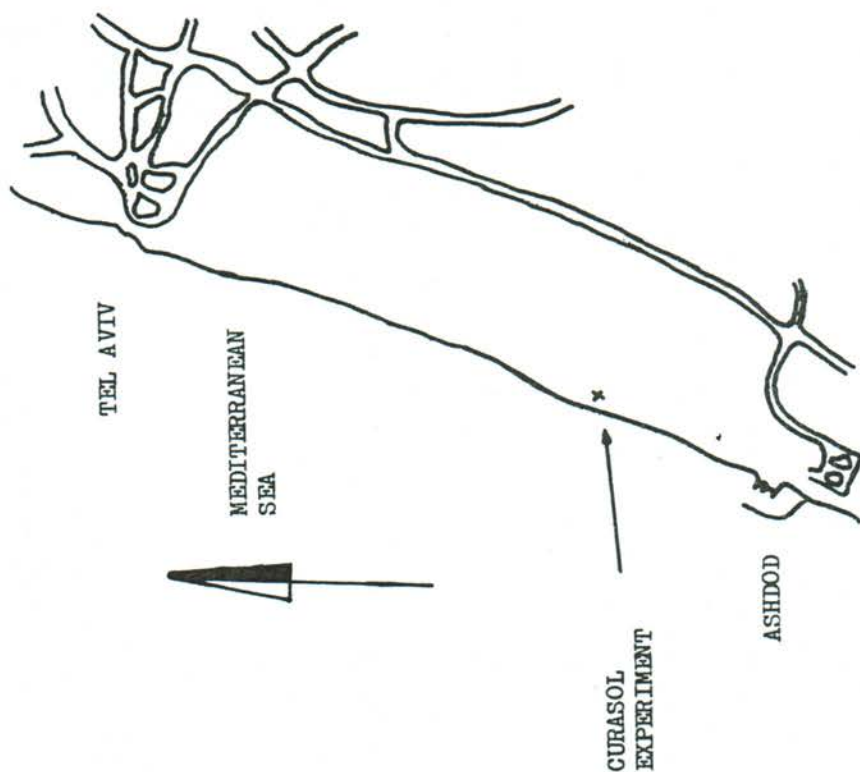
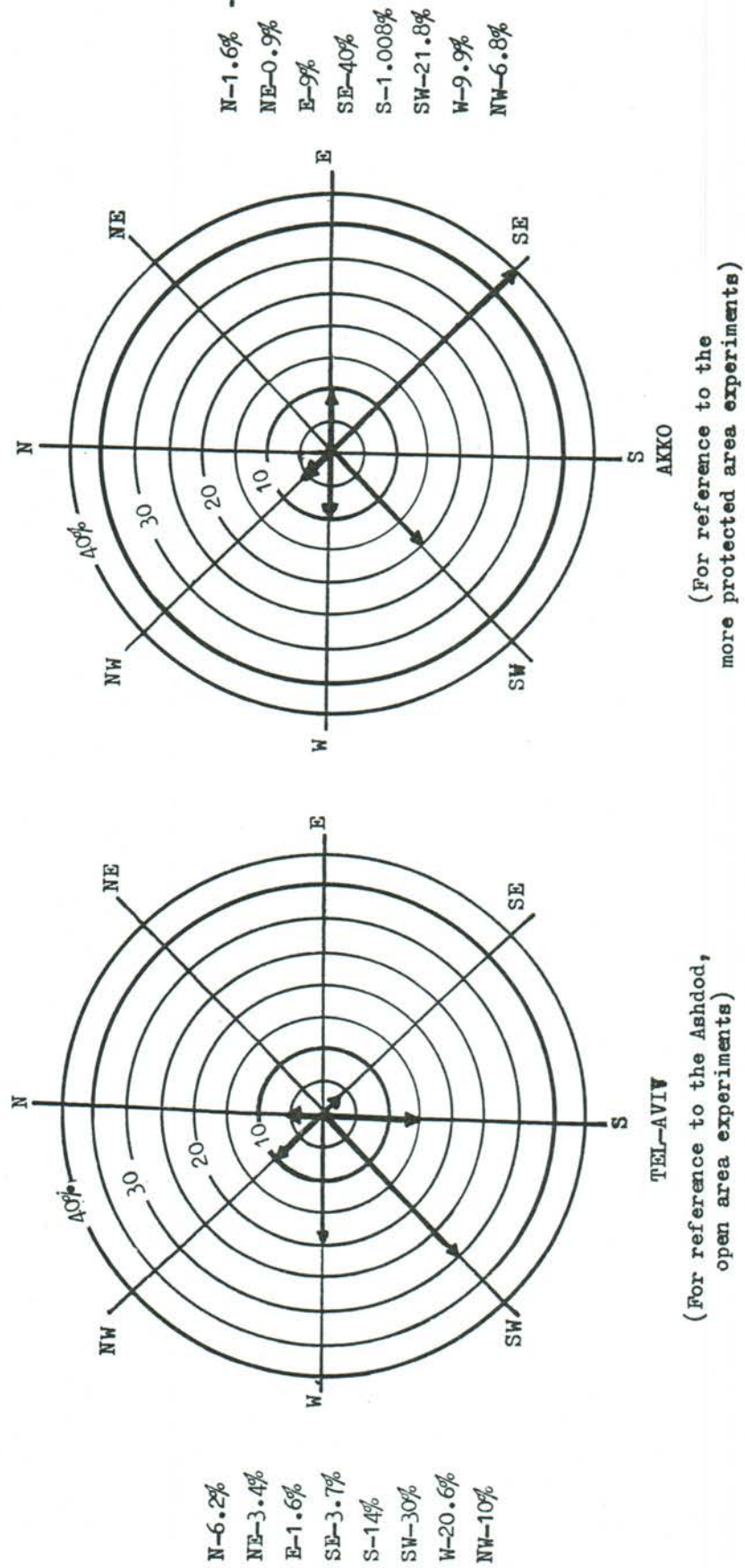


Figure 5: LOCALITY OF CURASOL
EXPERIMENT NEAR ASHDOD
(The open, drifting site)

Figure 7: RELATIVE TRANSPORTING CAPACITY OF THE SAND MOVING WINDS (ABOVE 3.3 BF) IN THE STUDY AREAS DURING DECEMBER-JANUARY-FEBRUARY (BASED UPON AVERAGE VALUES COVERING EIGHT CONSECUTIVE YEARS)



The data of the Tables 7-9 illustrate the following points:

- (i) the lowest minimum temperatures occur during January and February, with no significant difference between the Akko and Tel Aviv areas;
- (ii) maximum temperatures exceeding 30°C occur during the March to November period.

4. The Treatment at the Haifa Site

For the experiment at the Sand Dune Control Station (the more protected area) each plot of one dunam was divided into three equal sections, each section receiving the following treatments:

- the sowing of sand binding plants with Curasol spraying with the sowing done by hand in furrows 4-6 cm deep at a rate of 10 kg of seeds per hectare;
- broadcasting of the same seeds above the surface, with Curasol spraying;
- the same sowing without Curasol (control plot).

The Curasol in all tests has been dissolved at a rate of 50 gr Curasol plus 150 gr water per square metre.

5. Results and Conclusions for the Haifa Site

Tests were carried out in respect to the following factors:

- the consistency of the crust and its resistance to environmental factors such as rainfall, intensive sun radiation and high soil and air temperature;
- plant growth above the crust; and
- plant protection against birds.

5.1 The spray material and plant growth

The observations were made from the time of treatment, 26 December 1969, until 26 February 1971. Table 10 summarizes the observations on the plants. The findings led to the following general conclusions:

- at air temperatures between 10 and 24°C the Curasol spray coagulates within two hours (the spraying produces a firm film, which is colourless and 2-3 mm thick). It is solid, but at the same time elastic enough to adhere itself to the plant. The slight trampling of a man does not crumble it. After three months cracks appeared, but they were all slight, without breakage of the film cover as a whole. The same condition was maintained until the end of the observations;
- one year after the spraying, at certain places, the crust has been destroyed by trampling of dogs. Heavy rainfall, wind or high air soil temperatures did not disturb the crust;
- eight days after sowing and spraying, germination attained a rate of 40 percent. Three months afterwards germination reached 70 percent;
- at every date during the test, the plants with Curasol showed a better development in height than those without Curasol treatment;
- the colour of the plants at each date of observation was of a darker green in the treated plots than in the control plots;

- the number of plants per running metre under Curasol film was approximately one and a half to two times larger per running metre owing to the fact that since the beginning of the experiments, seeds were better protected against birds and blowing out by the wind. This also relates to the protection of the roots of the young seedlings, which in loose sand, without any crust protection, are shaken by wind, hindering the normal development of the plant and its establishment;
- the superficial sowing, with the help of the Curasol spray, did not succeed; poor germination occurred and most of the seeds were blown away.

Table 10

Height, colour and number of plants per square metre (the colour is estimated from 1-5 varying from palest to darkest green)

Date of observation	Height of Plants		Colour of Plants		No. of Plants per running m	
	With Curasol cm	Without Curasol cm	With Curasol 1-5	Without Curasol 1-5	With	Without
5.4.70	11	9	5	4	73	43
6.5.70	20	13	4	3	68	42
3.6.70	23	14	3	2	67	39
25.7.70	24	16	3	1	57	29
26.2.71	30	20	3	1	55	40

5.2 Soil temperatures following spraying

Table 11 illustrates some soil temperature observations for the sprayed and control plots for the dates indicated. These measurements showed that:

- in both depths and on both dates, the sand under Curasol attained a higher temperature than the uncovered sand;
- the differences were 4.6° - 4.8° at a depth of 5 cm. At a depth of 10 cm, the difference was 2.3° - 2.8°C ;
- even at relatively lower air temperatures (18.5°) the differences between Curasol covered versus uncovered surfaces remained the same;
- higher soil temperatures, at these application rates, were beneficial for plant growth, especially during the cold season.

Table 11

The soil temperatures beneath the Curasol crust at depths of 5 and 10 cm

Table of reading	Beneath Curasol depth		Control plot depth		Air temperature °C	Air humidity %
	5 cm	10 cm	5 cm	10 cm		
5.9.71 hr 12.00	37.6	30.6	32.8	28.2	33.5	53
26.10.71 hr 12.00	23.1	25.0	23.5	22.7	18.5	55

6. Results and Conclusions for the Ashdod Site

The more open site at Ashdod showed the following results (see Table 12):

- a) the development of most plants had been satisfactory and they attained a normal height and a good, dark green colour. Survival of the plants was satisfactory, except in cases where plants suffered from lack of water, especially Tamarix articulata;
- b) in spite of high wind velocities in winter months and shifting sand all around the experimental plots, the plants had been efficiently protected by the Curasol film. No out-blowing of the plant roots appeared;
- c) furthermore, the film showed a certain effectiveness in allowing shifting sand from the outside to glide across its surface, without accumulating. Too much sand accumulation would have buried the plants.

7. Summary

The following general conclusions may be drawn from the experiments at the two test sites:

- in the Curasol experiments at both sites, the film basically stayed intact, in spite of high wind velocities, sudden wind gusts, high rain intensities and intense values of radiation;
- the Curasol film is efficient for transplanted as well as for directly sown sand-binding species;
- the crust is efficient against bird attacks;
- soil temperatures were somewhat increased in the upper layer of the soil, but this was beneficial for plant growth, especially during the winter season;
- the film remained continuous and firm during the period from December 1969 until March 1971, without significant crumbling or cracking;
- the plants whose foliage received Curasol spray did not show any signs of damage;
- the Curasol product is not suitable for enabling superficial sowing of plants.

Table 12

Height, colour and number of surviving plants in open sand dune area experiment (Ashdod)

(Date of planting: 10.2.69)

Name of plant	Height cm	Colour 1-5	No. of surviving individuals in %	Name of plant	Height cm	Colour 1-5	No. of surviving individuals in %
<u>Polygonum equisetiforme</u>				<u>Lotus creticus</u>			
18.1.70	15	3	85	18.1.70	10	2	60
30.6.70	20	4	85	30.6.70	15	2	55
11.2.71	30	4	85	11.2.71	20	3	40
1. 8.71	35*	3	70	1. 8.71	30	2	30**
<u>Pennisetum dichotomum</u>				<u>Galenia secunda</u>			
18.1.70	30	2	60	18.1.70	15	4	60
30.6.70	35	2	40	30.6.70	20	3	20
11.2.71	35	1	20	11.2.71	25	2	5
1. 8.71	35	1	5***	1. 8.71	30	2	3*
<u>Ammophila arenaria</u>				<u>Calligonum comosum</u>			
18.1.70	20	1	15	18.1.70	20	3	50
30.6.70	30	2	10	30.6.70	20	2	40
11.2.71	40	2	8	11.2.71	30	2	17
1. 8.71	45	2	8	1. 8.71	40	1	10
<u>Artemisia monosperma</u>				<u>Zygophyllum album</u>			
18.1.70	60	5	90	18.1.70		4	80
30.6.70	70	5	90	30.6.70		3	25
11.2.71	75	5	95	11.2.71	40	3	25
1. 8.71	75	5	90	1. 8.71		3	20
<u>Retama roetam</u>				<u>Tamarix articulata</u>			
18.1.70	30	3	80	18.1.70	50	4	100
30.6.70	40	2	70	30.6.70	100	4	80
11.2.71	45	2	18	11.2.71	130	5	60
1. 8.71	45	2	15	1. 8.71	130	2	50****

*The plants were damaged by animals

**Suffered from drought

***Died

****The excellent growth caused a high water requirement, when water table sank, plants suffered heavily by drought

Table 13

A list of plant species at the Ashdod site

Name of plant species planted in the Curasol experiment near Ashdod	Number
<u>Polygonum equisetiforme</u>	300
<u>Lotus creticus</u>	200
<u>Pennisetum dichotomum</u>	650
<u>Galenia secunda</u>	300
<u>Ammophila arenaria</u>	200
<u>Calligonum comosum</u>	200
<u>Artemisia monosperma</u>	100
<u>Zygophyllum album</u>	100
<u>Retama roetam</u>	100
<u>Tamarix articulata</u>	50
Total	2,200