4. Sandy desertification

4.1 Spread and state

According to the former research reports and data, sandy desertification had developed rapidly in a large range only since the late of 1950's. Based on the different status from quantitative change to qualitative change, the desertified land can be classed in 4 degrees, such as slight(L), moderate(M), severe(S) and very severe(VS), and also can be divided in desertified farm land, rangeland and woodland or mixed land-above according to the major pattern of land use. The research results of a project on monitoring and assessing sandy desertification in the region, which was carried out and employed the methods of combination on the multitemporal remotely-sensed data applied and the natural-social comprehensive studied, has shown that the sandy desertification spread rapidly (Wang Tao, 1989, 1991, Zhu Che, Wu Wei, 1994). From Table 1.it can be found out that the development of desertified land was not only in the areas but also in the degrees. The total desertified area of higher degree, such as of moderate, severe and very severe have increased from 4,590 sq.km. in 1975 to 10,759 sq.km. in 1987, that was 6,169 sq.km more or 134.4% more. Meanwhile, the slight desertified land, on the contrary, has decreased from 17,512 to 12,995 sq.km. because most of those lands had expanded to the lands of moderate, severe and very severe. It has also been illustrated that there were very limited wasteland could be reclaimed.

Table 1. The development of sandy desertification in Bashang region of the North China

(unit: sq.km.)

Limited Class	Light			Moderate			Severe			Very Severe		
Time	1975	1987	± %	1975	1987	± %	1975	1987	± %	1975	1987	± %
Zhangbei	3049	2696	-11.6	261	685	162.1	41	130	217.1	–	–	
Shanyi	1374	1119	-18.5	63	274	335.0	–	155		–	–	
Kangbao	2555	1968	-22.9	463	829	79.1	105	289	175.2	–	–	
Guyuan	1951	1757	-9.9	112	326	191.1	39	132	238.5	–	–	
Fengning	696	480	-31.0	386	627	62.6	45	212	371.1	10	38	28
Weichang	439	259	-41.0	364	402	10.4	80	322	302.0	–	65	
Huade	1294	631	-51.2	337	602	44.0	80	435	443.8	–	105	
Xianghuang	671	237	-64.7	98	417	325.5	–	131		–	11	
Zhenbai	1184	949	-19.8	115	266	131.3	–	79		8	24	200
Taipusi	2332	1537	-34.1	271	1077	297.4	74	278	275.7	5	21	320
Zhenlan	552	502	-9.1	301	372	23.6	201	251	24.9	30	110	266.7
Duolun	1382	634	-54.1	741	1211	63.4	231	583	152.3	129	277	114.7
Total	17479	12769	-26.9	3512	7088	101.8	896	2997	234.5	182	674	270.3

4.2 Processes of sandy desertification

Sandy desertification had resulted from the vegetation degradation by overcultivating, overgrazing, wood collection. It had led to a general decrease in productivity of the land and in the accelerated degradation of the soil resource due to wind erosion in the region. The fine top soil was lost to wind erosion. The excessive loss of soil, nutrients, and sometimes even seeds from the ecosystem affects the capability of the vegetation to recover and crop agriculture to grow, and constitutes the principal mechanism of damage to the economy. The landscape of farmland and rangeland has been changed by the wind erosion/deposition from clear surface roughness and fresh sand sheets cover, bush-wood sand mounds to shifting sands and eroded lands inter-distributed with fixed and semi-fixed dunes, blowouted bush-wood dunes, and to eroded lands and drifting sands with ripples in the barchan dunes and barchan chains, abandoned farmland and degraded grassland, roughness surface with no vegetation cover. Results from the dynamic analysis of desertified maps, which was based on the map of 1975 and 1987 and the Arc/Info GIS, point out that, during that period, there were 816 sq.km. of rangeland have been developed directly to desertified farmland in different degree and 640 sq.km. to desertified rangeland. There were many changes and evolution from land use pattern to the areas and degrees among the different type of desertified land. Actually, some sites in the region, where some efforts have been made over decade for combating the processes, the desertified land has decreased not only from areas but also from intensities, although the reversed value was rather low compared with expanded areas (Wang Tao, 1989).

4.3 Causes of sandy desertification

It is no doubt that the human inappropriate land use should take mainly responsibility for the sandy desertification in the region. Meanwhile, it is also considered the climatic impact on the issue. For last 3 decades, the temperature has shown an increased trend, the rainfall has increased in 1970s as against 1960s and decreased in 1980's against 1970's (Table 2.). Specially, during seventies and eighties those changes were favourable for the process of sandy desertification. But it is still not so easy to determine its contributed rate.

Table 2. Changes of temperature and precipitation in Bashang region (1960 – 1989)

Station	Temperature (℃)		Precipitation (mm)	
	70's — 60's	80's — 70's	70's — 60's	80's — 70's
Zhangbei	0.318	0.054	16.70	–44.46
Shangyi	0.000	0.867	67.06	–70.40
Kangbao	0.170	0.120	35.26	–56.22
Guyuan	0.598	0.137	64.20	–57.70
Fengning	0.328	0.112	53.30	–75.40

5. Conclusion

The areas of sandy desertified land have developed very quickly from 1975 to 1987 in Bashang region of the North China as the serious desertified lands (in degree of moderate,severe and very severe) have increased 6,169 sq.km.. The major dynamic causes were human excessive land use such as overreclaiming, over grazing and wood collection. Although it is believed that the small variation of temperature and precipitation based on the semi-climate could accelerate the process of land degradation, the difficult thing is we don t understand how much its contribution was. It has been proved that the multitemporal remotely-sensed data applied could be effective tool for studying sandy desertification.

References

Wang Tao (1989): Journal of Desert Research, 9(1): 113–136.
Wang Tao (1991): Journal of Desert Research, 11(3): 39–45.
Zhu Che, Wu Wei (1994): Journal of Desert Research, 14(4): 98–103.
Zhu Zhenda, Liu Shu (1989): Desertification and its rehabilitation in China, Science Press, Beijing, 170.
Zhu Zhenda, Wang Tao (1990): Acta Geographica Sinica, 45(4): 430–440.
Zhu Zhenda, Wang Tao (1992): Quaternary Sciences, 2: 97–106.

沙漠研究 5S, 183-186(1995)
Journal of Arid Land Studies

Evaluation of Multitemporal Techniques to Map and Monitor Land-Cover Change in Arid and Semi-Arid Environments

Yuji HIROSAWA* and Stuart E. MARSH**

Abstract - Multitemporal techniques to characterize vegetation type and to detect land-cover change based upon phenological characteristics were examined using NOAA AVHRR data. We introduce the concept of a vegetation vector, which is defined by the first two principal components derived from a three year multitemporal NDVI dataset. This vegetation vector was successfully used to characterize vegetation type and could be used to explain the seasonal change of vegetation. The vegetation vectors were also created for each year and the inter-annual difference of the vector could be used to explain both changes in the amount of vegetation and the pattern of seasonal change.

Key Words: NOAA AVHRR, Principal Component Analysis, Arid Environments, Multitemporal Studies

1. Introduction

Multitemporal satellite images are an important source of information for the analysis of land-cover change, particularly when vegetation is used as an index of change. Any attempt to analyze this change must be able to separate seasonal from inter-annual phenological differences which requires the use of multitemporal data from more than two years. This research project applied principal component analysis to develop a new multitemporal technique to independently detect seasonal and inter-annual vegetation change. Changes in vegetation were also related to precipitation for a study site in Arizona.

2. Data

Data from the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) satellites have been used by many researchers to compile multitemporal data sets for the evaluation of vegetation. The data set used in this research is the biweekly maximum value composite images of the Normalized Difference Vegetation Index (NDVI) prepared by the U.S. Geological Survey EROS Data Center. NDVI is defined as

$$NDVI = (N_{IR} - R_{ed}) / (N_{IR} + R_{ed})$$

where N_{IR} and R_{ed} are reflectance factors in the near-infrared and red regions of the electromagnetic spectrum. Each image was compiled from multiple dates of data over a two week period by compositing pixels exhibiting the maximum NDVI in order to reduce the effects of cloud contamination and atmospheric attenuation. One composite image covers the conterminous U.S. with a 1 km cell size and data from 1989 - 1994 are available on CD-ROM.

A rectangular study area which covers the entire state of Arizona was extracted for our research. The extracted area consists of 636 columns x 759 rows and we utilized data from 1990, 1991 and 1992 which have 19, 21 and 20 composite images respectively.

To examine vegetation communities within the study area, a map of the Natural Vegetation Communities in Arizona (Brown and Lowe, 1964), was utilized. Climatic data available from the National Climatic Data Center Summary of The Day (EarthInfo Inc.,1994) was utilized to extract monthly precipitation data.

3. Characterization of Vegetation Types using a Vegetation Vector

3.1. Principal Component Analysis Principal Component Analysis (PCA) of the multitemporal NDVI data set was applied using the correlation matrix, which serves to standardize comparisons. PCA was applied to the entire Arizona study area. Figure 1 shows the coefficients of the eigenvector of the first two principal components (PCs). The coefficients of the first PC were positive and displayed

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limited fluctuation which appears to correspond to the natural variation of vegetation in the study area. The coefficients of the second PC showed a periodic cycle which reflects the seasonal change pattern of the vegetation.

The eigenvalues of the first and the second PCs were 48.53 and 2.98, and their ratios of contribution were 80.9 % and 5.0 % respectively. PCA can thus extract small factors from the data, and the second PC, though contributing only 5 % of the variance to the total multitemporal data set, clearly characterizes seasonal variation.

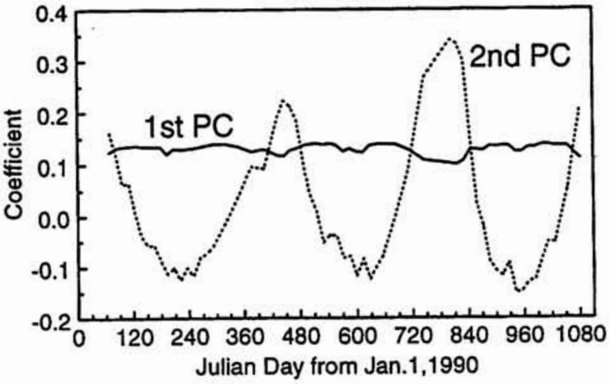


Figure 1. Coefficient of Eigenvectors of the First Two Principal Components. PCA was applied to three year dataset.

We also applied PCA to each vegetation cover found in the study area on an individual basis based upon the Natural Communities map. However, the meaning of the first two PCs did not show the same clear patterns as when the analysis was applied to the entire study area. This would indicate that among these community designations, seasonal patterns of change are also unique. Thus, it is important to note that the analyzing area must contain several kinds of seasonal change patterns when applying PCA.

3.2. Phenological Characterization of Vegetation Types Two of the most important indices of the characteristics of vegetation communities are the quantity or vigor and seasonal patterns of change. These can be quantified using the score of the first two PCs.

The concept of the vegetation vector is shown in Figure 2. When a pixel's first and second PC standardized scores are projected onto Euclidean space, its position can explain the phenological characteristic of the pixel. The position of the plot can be alternatively defined using distance and direction from the center point, thus characterizing the combined scores as a vector. This vector can then be used to express the phenological characteristic of the pixels or its vegetation type.

Figure 3 shows the histograms of the direction of the vegetation vector for three of the representative vegetation types within Arizona and Figure 4 shows the trend of mean NDVI for the corresponding vegetation types. The direction was categorized as shown in

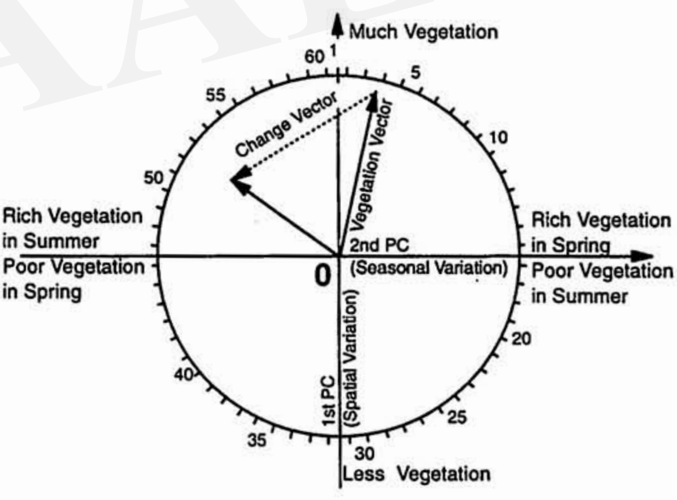
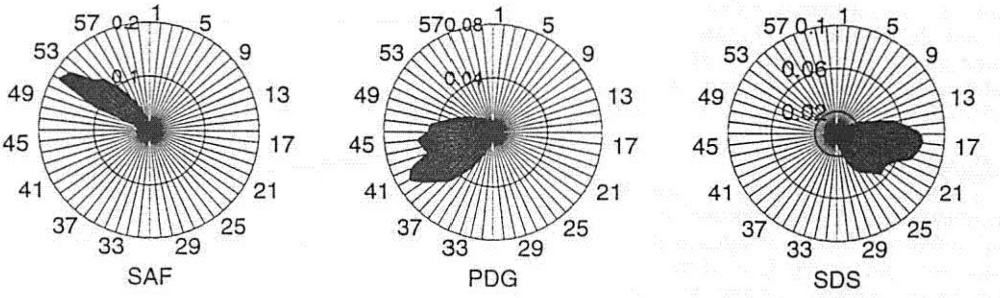


Figure 2. Conceptual Diagram of Vegetation Vector and its Change Vector. Values outside the circle categorize the direction of the vegetation vector.



SAF:Spruce - Alpine Fir Forest (770 pixels)
PDG:Plains & Desert Grassland (65,862 pixels)
SDS:Sonoran Desert Scrub, Arizona Upland (47,906 pixels)

Figure 3. Histograms of Angle of the Vegetation Vectors. The direction of angle was categorized as shown in Figure 2. Frequency is the ratio to the number of pixels among each vegetation community.

Figure 2. The profile of the histogram can be used to explain the differences in the phenological characteristics of these vegetation types.

4. Change Vector

Annual vegetation vectors were created by applying PCA to three years of data separately. The coefficients of the eigenvector of the first two PCs are shown in Figure 5. The same derived quantities from the PCA as described above were also extracted here.

Figure 6 shows the change vector for a test site on the Santa-Rita Experimental Range, where vegetation condition and pattern is very sensitive to rain-fall and which falls within the Desert Grassland community. Significant change is evident in the second PC between 1990 and 1991/1992, however the first PC exhibits only a slight change. Figure 7 shows the monthly trend of precipitation and NDVI for the Santa-Rita test site and corresponding to the area in Figure 6. The area received significantly more precipitation from June to August 1990 compared to the same period in 1991 and 1992. The peak of NDVI from August to September in 1990 was also higher. As this change

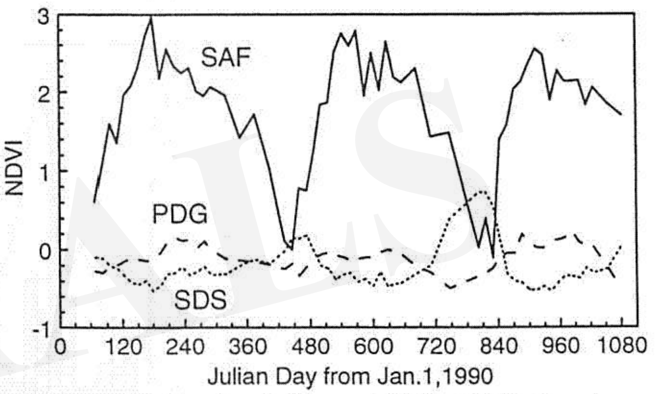


Figure 4. Trend of Mean NDVI. NDVI has been standardized. The name of vegetation type was shown in Figure 3.

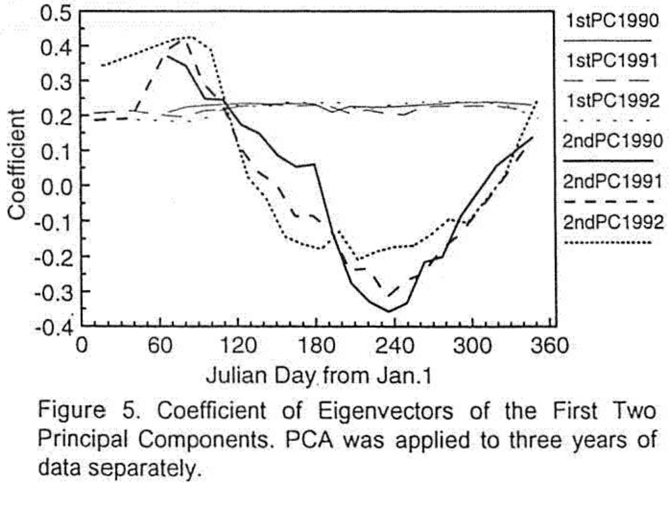


Figure 5. Coefficient of Eigenvectors of the First Two Principal Components. PCA was applied to three years of data separately.

contributes as a negative factor to the second PC score (see Figure 5), the score of the second PC in 1990 was significantly smaller than that of 1991 and 1992.

5. Conclusion

These preliminary results demonstrate that PCA applied to the multitemporal NDVI images and the vegetation vector we derived from the first and second standardized PC scores are a useful means of characterizing vegetation type based on phenology. The vegetation vector and its change vector can be used to separate vegetation change into seasonal and inter-annual components.

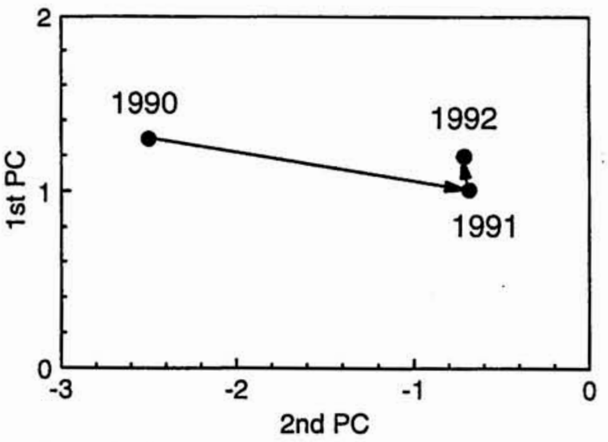


Figure 6. Change Vector on Santa-Rita Experimental Range

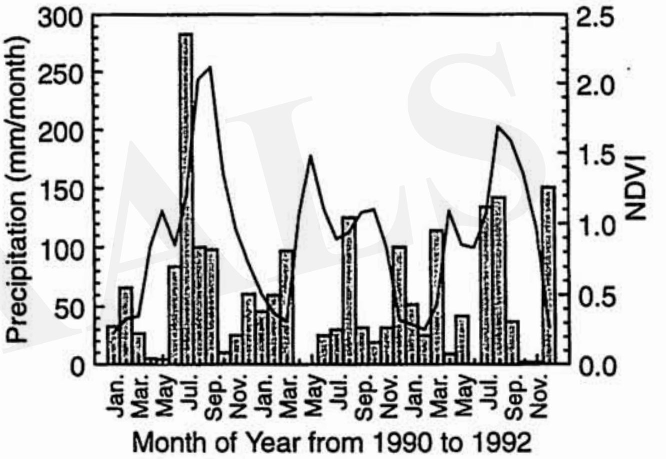


Figure 7. Monthly Trend of Precipitation and NDVI on Santa-Rita Experimental Range. NDVI has been standardized.

沙漠研究 5S, 187-190(1995)
Journal of Arid Land Studies

EFFECTIVE POROSITY OF A SEDIMENTARY ROCK DETERMINED BY A FIELD TRACER TEST USING TRITIUM AS A TRACER

Hiroyuki Ii*, Yoshiyuki Ohtsuka* and Shinya Misawa**

Abstract - We measured effective porosity values from the tritium concentration distribution for the groundwater and measured specific yield. Effective porosity and specific yield were concluded to be groundwater flow velocity. Some water stored in a sedimentary rock can be used only by a drainage accompanied with rapid groundwater level change. However, after groundwater level change pore water continued to be drained. Therefore, most water stored in a sedimentary rock can be used for a long time.

Key words:Effective porosity, longitudinal dispersivity, tritium, tracer test

1. Introduction

A lot of groundwater pumped up through deep boreholes and wells was used for desert development. Planned or controlled pumping of groundwater is necessary because the water table lowers and the water content of the aquifer decreases. It is necessary for the controlling of pumping to clear groundwater flow. Effective porosity which was necessary for estimation of groundwater flow and storage volume of underground dam, was analyzed by a tracer test.

Tritium, which is an unstable isotope with a half life of 12.43 years, is produced naturally in the earth's atmosphere from reactions between cosmic-ray-produced neutrons and nitrogen. Free tritium most commonly collides with O_2 and enters the water cycle. Therefore, rainwater contains a detectable concentration of tritium. The tritium concentration for groundwater depends on recharge time because the source of the tritium for the groundwater is only rainwater and tritium is an unstable isotope. The recharge time can be calculated from effective porosity values, hydraulic conductivity, the groundwater level, and dispersion coefficient. We estimated effective porosity values from the tritium concentration distribution for the groundwater. The Matsumoto tunnel, approximately 2000 m in length, was being constructed within a plateau north of Matsumoto city in central Japan. Tunnel construction began in October 1990 and finished in April 1992. The total volumes of seepage water at the west side and the east side of the tunnel were 1.2 and 1.6 million tons. The porosity values determined by the weight of samples in both water saturated and dry conditions were 7 ～ 15 %.

2. Tritium concentration

Fig. 1 shows the change of tritium concentration. Sampling seepage water within a tunnel under construction is an effective way to get groundwater without mixing the groundwater at the different positions. The groundwater table lowered during tunnel digging at the tunnel. Thus, seepage water within the tunnel is not originally at the sampling point before tunnel digging but at the upper stream. The seepage water is younger than the groundwater at the sampling points before digging. The tritium concentrations for the tunnel seepage water were under 0.3 T.U. except for some water whose NO_3^- concentrations were detectable and were thought to be a mixing of surface water and groundwater (Ii and Misawa, 1994). If the tritium concentration for precipitation is over 6 T.U., the recharge time for the tunnel seepage water is more than 50 years.. The flow velocity is less than 1×10^{-5} cm sec^{-1} (150 m ÷ 50 years) as the length between the tunnel and the surface of the plateau is 150 m.

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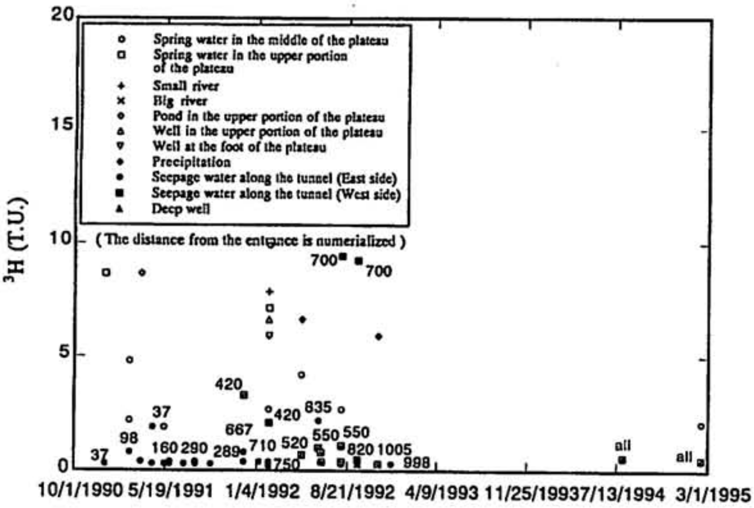

Fig. 1 Change of ^{3}H concentration in the sampled water

3. Analysis

The tritium concentration for the precipitation was about 10 T.U. because the tritium concentration for precipitation in the Tokyo area was 10 T.U. 50 years ago. The groundwater level was assumed to equal with the topographical feature. As the groundwater level did not change before tunnel construction, the seepage analysis was assumed to be in a steady-state groundwater flow condition. As the plateau was surrounded and divided from the other plateau by rivers, the rivers were assumed to be impermeable boundaries for the analytical area. The analytical area was assumed to be a uniform medium because there was no remarkable change found under construction.

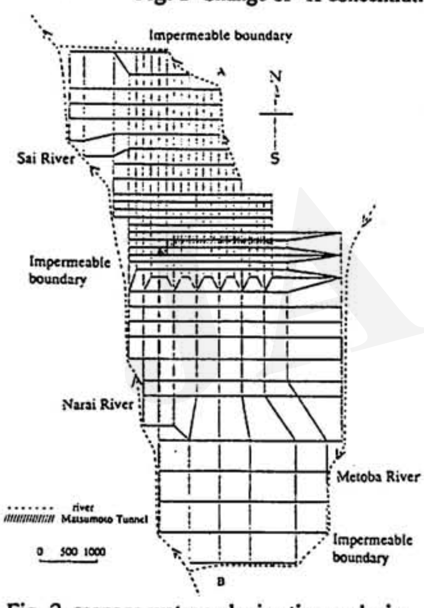

Fig. 2 seepage water and migration analysis model at the horizontal section

Table 1 Parameters and boundary conditions used in the seepage and migration analysis

Groundwater level	Heights of ground surface (constant)
Boundary condition	Impermeable
Tritium concentration of ground surface	10T.U. (constant)
Decay constant	1.77×10^{-9} (sec^{-1})
Hydraulic conductivity	$2.8\times10^{-9} \sim 2.8\times10^{-5}$ cm sec^{-1}
Effective porosity	Maximum 15%
Longitudinal dispersivity	1, 12, 100m

3.1 Seepage analysis

Fig.2 shows the seepage and migration analysis model at the horizontal section. There are 6 layers in the model and the sum thickness of these 6 layers is 450 m. Table 1 displays the parameters and boundary conditions used in the seepage and migration analysis. The equation governing steady-state groundwater flow in a three-dimensional system is generally given as uniform medium,

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=0 \qquad (1)$$

where ϕ : piezometric head, and x, y, z : Cartesian coordinates. The system boundaries are impermeable excepting the tunnel and springs. Boundary conditions can be given as follows,

$$\phi = \phi_0 \qquad \text{at the the tunnel and springs} \qquad (2)$$

where ϕ_0 : steady-state piezometric head level . A seepage analysis was performed using FEM in eq. (1). The analysis was simplified using the boundary conditions described by eq. (2).

3.2 Migration analysis

A coupled equation steady-state governing groundwater flow and advection-dispersion in a three-dimensional system is given as follows,

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial x}(D\frac{\partial C}{\partial x})+\frac{\partial}{\partial y}(D\frac{\partial C}{\partial y})+\frac{\partial}{\partial z}(D\frac{\partial C}{\partial z})-\frac{\partial}{\partial x}(VxC)-\frac{\partial}{\partial y}(VyC)-\frac{\partial}{\partial z}(VzC)+\frac{F}{\varepsilon}-\lambda c \quad (3)$$

$$Vx=vx/\varepsilon, Vy=vy/\varepsilon, Vz=vz/\varepsilon \qquad D=\alpha\ |V|,\ \ |V|=\sqrt{Vx^2+Vy^2+Vz^2}$$

where ε : effective porosity value, C : concentration, D : dispersion coefficient, α : longitudinal dispersivity, λ : decay constant, Vx, Vy, Vz : actual velocity in the x, y and z directions, and vx, vy, vz : apparent velocity in the x, y and z directions. The dispersion coefficient is isotropic. The system boundaries are impermeable except at the borehole.

$$F = F_0 \text{ at the borehole} \qquad (4)$$

Where F : flux of mass ($\Delta C/\Delta t$), and F_0 : flux of mass at the borehole. A migration analysis was performed using FEM and the boundary conditions described by eq.(3).

4. Results and discussion

In this tracer test, from the governing eq.(3) and the initial and boundary conditions, effective porosity values, longitudinal dispersivity and hydraulic conductivity are unknown parameters for this migration analysis. Longitudinal dispersivity is empirically about one tenth of the distance between the tracer injection point and observation point according to Pickens and Grisak (1981a, b). As the maximum distance between the surface on the plateau and the tunnel was 200 m, three longitudinal dispersivity values of 1 m, 12 m and 100 m were chosen. Especially, 12 m longitudinal dispersivity and 0.48 percent effective porosity value were determined at the Matsumoto tunnel by Ii (1995).

Even if longitudinal dispersivity varies from 1 m to 100 m, when the effective porosity value is 10 percent and hydraulic conductivity is less than 5.6×10^{-6} cm sec^{-1}, the analyzed tritium concentration distribution at the tunnel is in accordance with the measured results (Fig.3, 4). Therefore, when the flow velocity value is 1×10^{-5} m sec^{-1}, the effective porosity value coincides with the porosity value. At the Matsumoto tunnel a tracer test was performed by injecting a Br^- solution into a borehole during construction by Ii and others (1993), Ii and others (1994) and Ii (1995). The calculated effective porosity value was 0.48 percent and the flow velocity was 1.8×10^{-2} cm sec^{-1}.

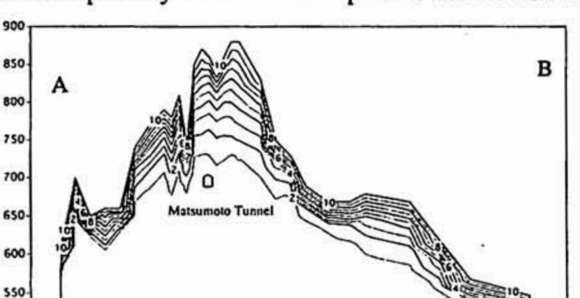

Fig. 3 Analyzed ^3H concentration distribution
(A-B sectional plan, α=1m, ε=10%, K=5.6×10^{-6} cm sec^{-1})

If tunnel seepage is free water in the rocks unsaturated during tunnel construction, specific yield value is calculated to be 0.6 percent by the total volume of the tunnel seepage and the total volume of the rock unsaturated during tunnel construction. The specific yield value was smaller than the porosity value (7～15 percent). However, the seepage water was derived from unsaturated rock which had been already drained during the groundwater level change. The tritium concentration for the seepage water, was 0.6 T.U., indicated that

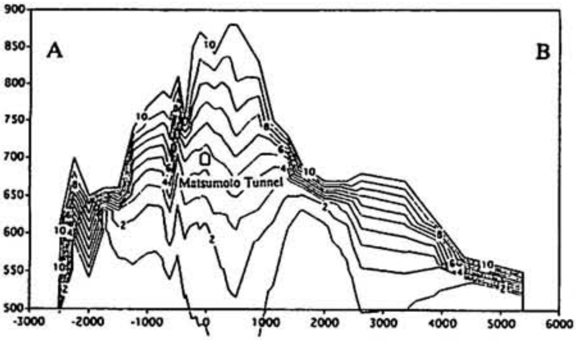

Fig. 4 Analyzed ^3H concentration distribution
(A-B sectional plan, α=1m, ε=10%, K=2.8$\times 10^{-5}$ cm sec^{-1})

the seepage water was not surface water. Therefore, specific yield value increased, as the time after the groundwater level change elapsed. Thus specific yield value is due to drainage time. During groundwater level change, 0.6 percent pore water was drained and after groundwater level change pore water continued to be drained.

Thus, some water stored in a sedimentary rock can be used only by a drainage accompanied with rapid groundwater level change. However, after groundwater level change pore water continued to be drained. Therefore, for a long time most water stored in a sedimentary rock can be used.

5. Conclusion

When the flow velocity was more than 1.8×10^{-2} cm sec^{-1}, the effective porosity value was smaller than the porosity value. However when the flow velocity was 1×10^{-5} cm sec^{-1} in the same area, the effective porosity value coincided with the porosity values. Therefore, effective porosity value is concluded to be due to groundwater flow velocity.

Specific yield value during groundwater level change was 0.6 percent. However as pore water continued to be drained after groundwater level change finished, specific yield value became larger than specific yield value only during groundwater change.

REFERENCE

Ii H, Ishikawa Y, Sugihara K and Utsugida Y (1993) Estimation of scale effect on effective porosity and longitudinal dispersivity of a Tertiary sedimentary rock by laboratory tracer tests and a field tracer test. Hannover : International Association of Hydrogeologists. 4 ; 153-162

Ii H and Misawa S (1994) The groundwater chemistry within a plateau neighboring Matsumoto city, Japan. J. Environmental Geology. 24 (3) : 166-175

Ii H, Misawa S and Kawamura R (1994) Effective porosity, longitudinal dispersivity and hydraulic conductivity of a sedimentary formation determined by field tracer testing, three-dimensional groundwater flow and advection-dispersion FEM : Proceeding of the 7th congress of the International Association of Engineering Geology. A.A.Balkema Publishers, Rotterdam : 4213-4221

Ii H (1995) Effective porosity and longitudinal dispersivity of sedimentary rocks determined by laboratory and field tracer tests. J. Environmental Geology .25 (2) :71-85

Pickens JF and Grisak GE (1981a) Scale-dependent dispersion in a saturated granular aquifer. Water Resource Research. 17 (4) : 1191-1211

Pickens JF and Grisak GE (1981b) Modeling of scale-dependent dispersion in hydrogeologic systems. Water Resource Research. 17 (6) : 1701-1711

沙漠研究 5S, 191-194(1995)
Journal of Arid Land Studies

Tracing the movement of sand salts during evaporation through a cotton cloth core and sand and polymer tube inserted into sand using three different anions as tracers

Yoshiyuki OHTSUKA*, Hiroyuki II*, Tetsuo OGAWA**, Yukuo ABE** and Tomoharu YAMAGUCHI**

ABSTRACT - The movement of sand salts through both a cotton cloth core and a sand and polymer tube stuck into sand during evaporation was studied using three kinds of anions as tracers. When the cotton cloth core was stuck into the sand, salt water was mainly transported from the mid and lower depth sands to the upper section of the cotton cloth core through the mid and lower sections of the cotton cloth core. A little salt water was transported from the lower sand to the surface sand and from the surface sand to the cotton cloth core. When the sand and polymer tube was stuck into the sand, salt water was mainly transported from the lower sand to the surface sand. At the beginning of evaporation, the surface sand and polymer tube was dried up. There was no migration toward the sand and polymer tube buried in the sand from the surrounding sand.

Key Words : evaporation, migration, tracer, desert, salt

1. Introduction

Salt accumulation in soil is a serious problem for agricultural areas in arid and semi-arid lands. Although leaching soil is an effective method to rid excess salts of soil, leaching requires a lot of water and drainage produced by leaching must be dealt with (FAO/Unesco 1967, USA National Academy Sciences 1974). Abe *et al* (1992) and Ii *et al* (1993) studied new methods of accumulating salt within a paper core and a stick which were inserted into sand. These methods used only a little water which the sand needed to be saturated with. After the sand was saturated with water, the salt which was in the sand during evaporation was accumulated in a paper core and stick. As the apparatus of the previous experiments was very small, the larger apparatus was utilized for this study. Three kinds of anions were used as tracers and injected into different positions in the sand and salt migration within the sand was studied in detail.

2. Experimental method

2.1 Materials

Fig.1 shows the Wagner pot (1/2000a and 250 mm in diameter) with an inner diameter of 250 mm and a height of 300 mm. The Wagner pot was filled with a 18.5 to 19.0 kg sand and 3.7 to 3.8 kg NaCl solution whose concentration was 0.5 % as the sand was saturated with water. The original water content was about 0.28 g cm^{-3}. The dry density and bulk density in the sand were 1.4 and 1.7 g cm^{-3}. The sand was river sand whose true gravity density was 2.69 g cm^{-3}. The initial salt content in the sand was negligible. A cotton cloth and sand with absorbent polymer were used for the experiment because they were porous and absorbed a lot of water. The cotton cloth was coiled around a wooden stick. Its length was 350 mm and diameter was 38 mm. The original water content was 0.4 g cm^{-3}. A cotton tube was filled with a mixture of 95 % sand (Flattery quartz-sand from Australia) and 5 % absorbent polymer. Both its ends were closed. Its length was 300 mm and diameter was 40 mm and the dry density was 1.5 g cm^{-3}. The original water content was 0.85 g cm^{-3}. This is termed sand and polymer tube.

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A cotton cloth core and sand and polymer tube saturated with a distilled water were inserted into the center of the sand. A 20 cm^3 NaBr solution whose concentration was 5 % was injected into the center bottom of the sand. A 20 cm^3 Na_2SO_4 solution whose concentration was 5 % was injected into the boundary of the sand and the Wagner pot 12 cm in depth.

2.2 Method

The Wagner pots were dried in the soiltron which was a controlled glasshouse for soil environment research at the farm in the University of Tsukuba. The atmospheric environment within the soiltron could be conditioned with the air-conditioner, but during the experimental period, the soiltron was being naturally ventilated with opening the top and side windows. During the experiment, the weights of the Wagner pots were measured. At each degree of saturation, the Wagner pots were dismantled and separated as shown in Fig.1. Distributions of water content were determined by weights in both water saturated and dry conditions and Cl^-, Br^- and SO_4^{2-} concentrations were determined by ion exchange chromatography for the cotton cloth core, sand and polymer tube and sand.

3. Experimental results and discussion

3.1 Cotton cloth core

The numbers in Fig.2 show each degree of saturation and water content distributions in the sand and the cotton cloth core. The numbers in Fig.3,4 and 5 show each degree of saturation and Cl^-, Br^- and SO_4^{2-} concentration distributions in the sand and the cotton cloth core on a dry basis. The water content of sand decreased from the surface sand to the deeper sand. However the water content in the cotton cloth core was kept to be high and uniform (homogeneous). From 100 % to 42 % degree of saturation, the water content in the cotton cloth core was unchanged to be 0.25 ～ 0.4 g cm^{-3} but the water content in the surface sand decreased to be from about 0.28 to 0.03 g cm^{-3}.

The Cl^- concentration in the upper section of the cotton cloth core and the surface sand increased markedly. However the Cl^- concentration in the surface sand surrounding the cotton cloth core decreased from 42 % to 60 % degree of saturation. The Cl^- concentrations in both the mid and lower depth sand decreased. The Br^- concentration in the injected sand decreased but the Br^- found in the cotton cloth core surrounding the injected sand increased. Especially the Br^- in the upper section of the cotton cloth core increased remarkably. Therefore, most Br^- migrated from the Br^- injected sand to the upper section of the cotton cloth core through the mid and lower sections of the cotton cloth core. The Br^- concentration in the surface sand increased. The SO_4^{2-} concentration in the injected sand decreased but the SO_4^{2-} found in the sand below the injected sand increased from 100 % to 80 % degree of saturation. Therefore firstly, SO_4^{2-} migrated in a downwards direction. From 80 % degree of saturation, the SO_4^{2-} concentration in the upper section of the cotton cloth core and the surface sand increased. As shown in Fig.6, during evaporation salt water was transported from the mid and lower depth sand to the upper section of the cotton cloth core through the mid and lower section of the cotton cloth core and a little salt water was transported from the lower sand to the surface sand and salt water was little transported from the surface sand to the cotton cloth core.

3.2 Sand and polymer tube

The numbers in Fig.2 show each degree of saturation and water content distributions in the sand and the sand and polymer tube. The numbers in Fig.3,4 and 5 show each degree of saturation and Cl^-, Br^- and SO_4^{2-} concentration distributions in the sand and the sand and polymer tube on a dry basis. The water content in the sand and the sand and polymer tube decreased from the surfaces. At 50 % degree of saturation, the upper sections of the sand and polymer tube were dried up. However the water content in the mid and lower sections of the sand and polymer tube were unchanged to be 0.7 g cm^{-3}. Even at 28 % degree of saturation, the water content in the lower section of the sand and polymer tube was 0.95 g cm^{-3}.

The Cl^- concentrations in the surface sands increased. However the Cl^- concentrations in the sand and polymer tube were unchanged to be very low. The Cl^- concentrations in the mid depth and the lower depth sands decreased. The Br^- concentration in the injected sand decreased from 100 % to 80 % degree of saturation. The Br^- concentration found in the sand surrounding the injected sand and in the surface sand increased. However the Br^- concentrations in the sand and polymer tube were unchanged to be very low. The SO_4^{2-} concentration in the injected sand decreased from 100 % to 80 % degree of saturation. The SO_4^{2-} concentrations in the surface sand increased. However the SO_4^{2-} concentrations in the sand and polymer tube were unchanged to be very low. As shown in Fig.6, salt water was mainly transported from the lower sand to the surface sand. There was no migration toward the sand and polymer tube buried in the sand from the surrounding sand.

4. Conclusion

As the cotton cloth core in the sand maintained a high water content, water lost by evaporation in the upper section of the cotton cloth core seems to have been supplied by capillaries from the sand through the cotton cloth core. Therefore, a lot of salt in the upper section of the cotton cloth core seems to have been accumulated from the sand.

As the sand and polymer tube was completely dry at the beginning of evaporation, the evaporation rate of water from sand and polymer tube seems to be larger than the velocity of capillary water movement through the sand and polymer tube. There was no migration toward the sand and polymer tube. Therefore, salt water moved mainly from the lower depth sand to the surface sand and the accumulated salt in the sand and polymer tube was very low.

5. REFERENCE

Abe, Y., Yamaguchi, T., Yokota, S., Ohtsuka, Y. and Ii, H. (1992) : The capture methods of the salt accumulated on the surface of soil. J. Arid land study. 2:19-27.

FELITSIANT, I.N. (1966) : Regularity of capillary movement of water and soil solutions in stratified soils. Translated from Russian, Israel Program for Scientific Translations, Jerusalem.

FAO/Unesco (1967) : *International source-book on irrigation and drainage of arid lands in relation to salinity and alkalinity*. 563-627.

Ii, H., Ohtsuka, Y., Ogawa, T., Abe, Y. and Yamaguchi, T.(1993) : Experimental study on salt capture method using a paper roll. J. Arid land study. 3:1-7.

USA National Academy of Sciences (1974) : *More Water for Arid Lands*. 73-137.

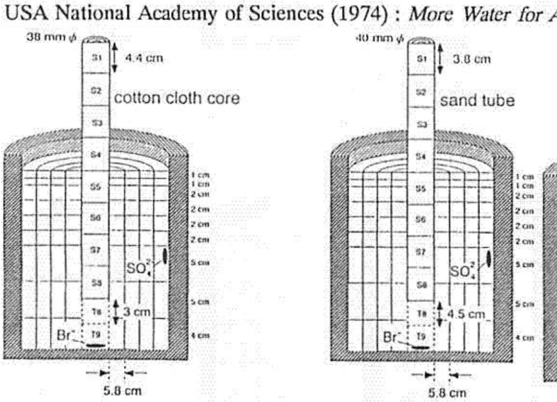

Fig.1 Test apparatus (Wagner pot filled with sand and cotton cloth core or sand and polymer tube)

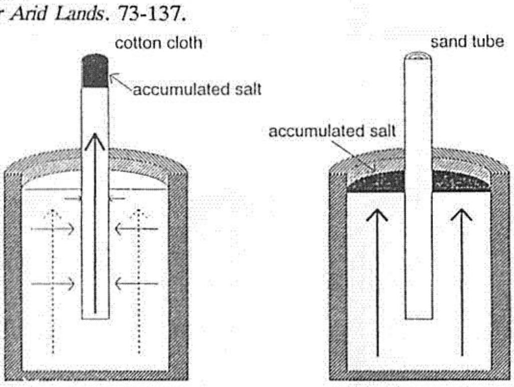

Fig.6 Schematics of migration in the cotton cloth core and sand and polymer tube

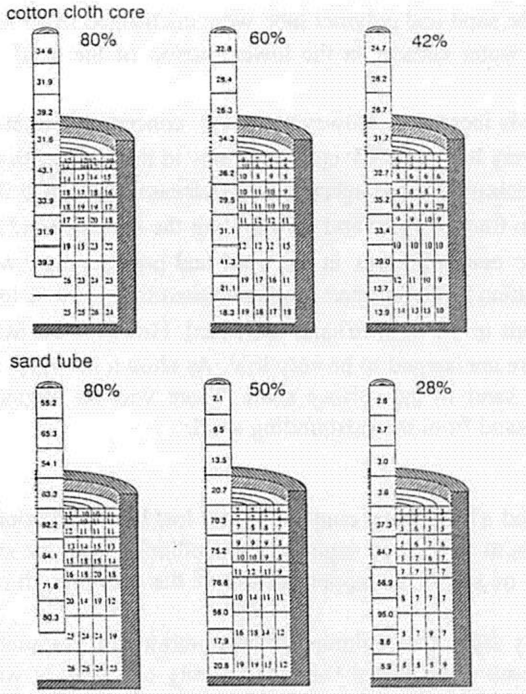

Fig.2 Changes of water content distributions (0.01g cm^{-3}) in the cotton cloth core and sand and polymer tube

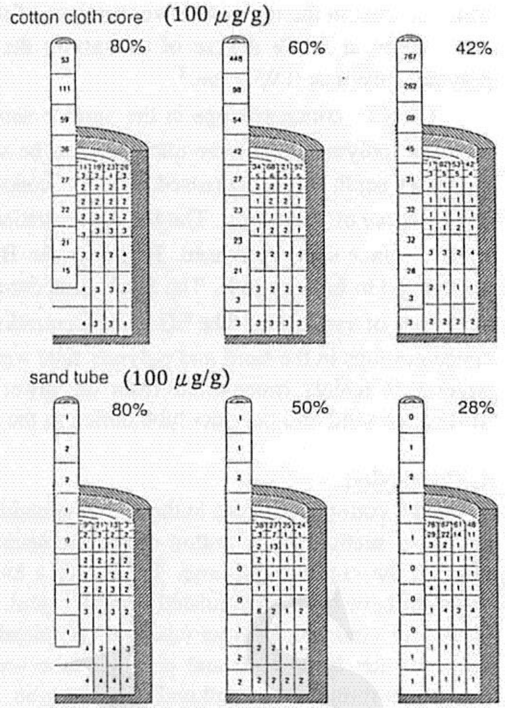

Fig.3 Changes of Cl^- distributions in the cotton cloth core and sand and polymer tube

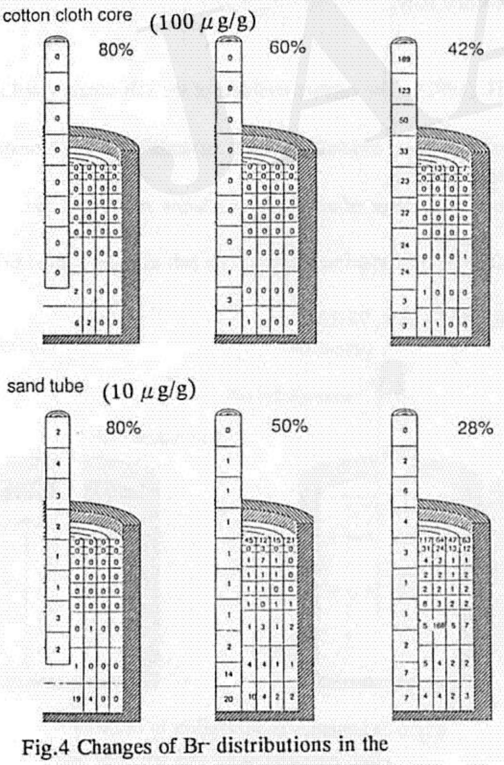

Fig.4 Changes of Br^- distributions in the cotton cloth core and sand and polymer tube

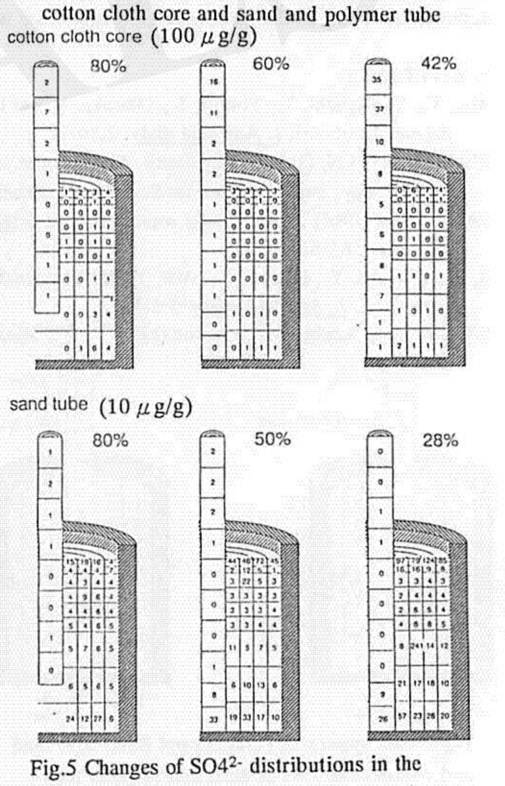

Fig.5 Changes of SO_4^{2-} distributions in the cotton cloth core and sand and polymer tube

沙漠研究 5S, 195-198(1995)
Journal of Arid Land Studies

Remediation And Rehabilitation Of Oil-Contaminated Lake Beds In Kuwait Desert

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Abstract- This paper summarizes the results obtained in first year of KISR/PEC three year joint research program. During this period, sustantial progress has been made: the site was selected, mine cleared, and investigated to determine the nature and distribution profile of contamination. Oil penetration was observed as deep as 2.5 meter deep in the subsurface soil and the contaminated material was excavated and hauled to a near by designated area for further treatment (3000 m^3 oil sludge, 2000 m^3 heavy to moderately contaminated soil and 5000 m^3 lightly contaminated soils). Bioremediation technology was selected for the treatment of the contaminated soil and three different methods are being field evaluated: landfarming, windrow composting soil piles and static piles fitted with forced aeration. Appropriate physical/chemical methods were also developed and tested in the laboratory for the treatment of the oil sludge and heavily contaminated soil which can not treated by bioremediation.

Key Words: Bioremediation, Physical/Chemical Treatment, Soil Washing, Surfactant

1. Introduction

Over six hundreds of Kuwait's oil wells were exploded during the Iraqi invasion and occupation of Kuwait in 1990, resulting in the worst environmental disaster in man's history. Oil gushed from the destroyed wells, forming more than 300 oil lakes covering 49 km^2 area. Successful efforts by Kuwait Oil company (KOC) resulted in the recovery of 22 million barrels of crude oil from these lakes but the lake beds still remain heavily contaminated. The remediation of the oil lake beds is now being actively considered so that oil contamination does not pose a critical health hazard to man and also to stimulate the restoration of the damaged ecosystem (Al-Awadhi et al., 1992). In July, 1994 a joint research program between Kuwait Institute for Scientific Research (KISR) and Japan Petroleum Energy Center (PEC) was initiated. The project is primarily intended to lay the foundation for rehabilitating Kuwait's environment through the field-scale demonstration of biological and physical-chemical technologies in order to obtain the necessary data to develop an "Action Plan" for the remediation of all-oil contaminated desert soil in Kuwait.

2. Site selection and Investigation

Following several visits to the Burgan oil field and meetings with Kuwait Oil Company (KOC), oil lake # 102 was selected for this project. The lake covers an area of more than 50 hectares and selection was based on several reasons including site accessibility, safety considerations, distance from main road, and many other site logistics. The lake bed has a thick oily sludge layer on the surface, followed by heavily contaminated subsurface soil. An area of one hectare (75 m x 135 m) of this lake was designated to the project. Sludge removal work started in December 1994 and due to the high viscosity of this material, it was practically impossible to mobilize field equipment into the oil lake during day time. Work was possible only during the early morning hours when the temperatures were cool enough to solidify the sludge, so it could be scooped by shovel loaders and dumped into tip trucks. The sludge were hauled and unloaded of the dump truck into the containment facility by the assistance of a backhoe fitted with a scraping bucket. The quantity of the oil sludge excavated from the one hectare area was found to be 3,013 m^3, suggesting an overall average thickness of 30 cm. The excavation of the contaminated material was completed in two phases. In the first phase, a total

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50 cm excavation depth from the top surface of the sludge level was achieved. This resulted in 2,012 m^3 of contaminated soil which required remediation, in addition to the oil sludge. During the second phase, additional 5,000 m^3 of lightly contaminated soil was removed.

The penetration depth of the oil contamination into the subsurface soil was investigated by collecting soil samples at various depth from several test pits, according to a predetermined grid. The degree of oil contamination was examined visually, documented by photographs and by chemical analysis. The soil was analyzed for total extractable material (TEM) by gravimetric analyses, total petroleum hydrocarbons (TPH), using IR spectrophotometric technique and Polyaromatic hydrocarbons (PAHs), using HPLC and spectrofluorphotometric methods. The oil distribution profile within the subsurface soil did not follow any clear pattern, possibly due to the variable geological nature of the Burgan area and the presence of gatch lenses in the subsurface soil. In some areas, oil penetration was limited to the first 50 cm and in other areas penetration was as deep as 2.5 meters. The concentrations of TEM in the analyzed samples, ranged between 20 to 60 % in the oil sludge and between 0.03 to 24.8 % (w/w) in the subsurface soil.

In addition to the above analyses, selected samples were extracted with freon and analyzed by Gas chromatograph fitted with flame ionization detector (GC/FID), to determine the general characteristics of oil contamination (Fig. 1). The results were compared with those of crude oil sample from the Burgan field (Fig. 2) and standard of authentic alkane compounds. The results indicated that the oil contamination has lost significant portion of the lower molecular-weight compounds (C8-C13), which is not surprising due to the exposure to harsh weather condition over an extended period. The observed shift in the elution pattern of hydrocarbons suggested also that extensive oil biodegradation occurred mainly in the surface soil, less degradation was observed at 20 cm and no degradation can be observed in samples taken at lower depth. This is possibly due to oxygen limitation which is necessary for active metabolism of petroleum hydrocarbons.

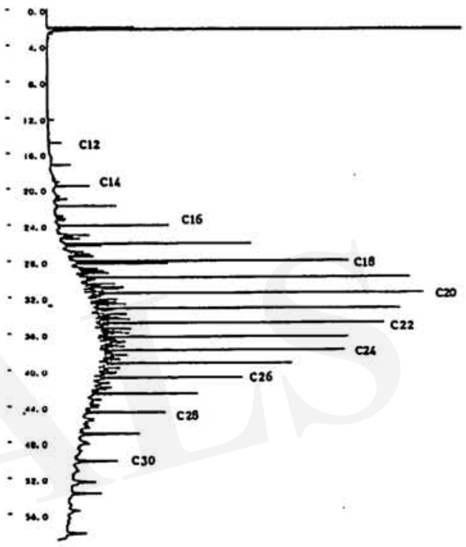

Fig.1 GC/FID-Chromatogram of the Soil Extract in Surface (0,C3)

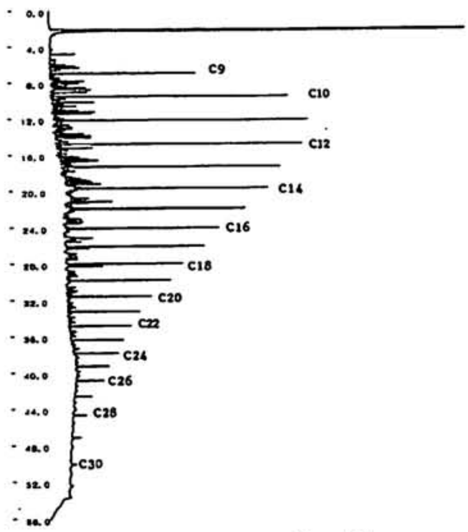

Fig.2 GC/FID-Chromatogram of n-alkanes in Kuwait Crude Oil

3. Soil Bioremediation

Biological treatment was selected for the treatment the soil with highest degree of contamination (the top 20 cm of soil following the sludge layer). The technology is also being assested for the lightly contaminated soil. The soil was initially screened to remove tarry material and stones and then supplemented with urea and phosphate fertilizer, to provide nitrogen and phosphorous sources for microbial growth. Compost and wood chips were also added to improve water retention capacity of the soil. The soil was then thoroughly mixed, using appropriate field equipment and used for the field bioremediation program. Three different types of bioremediation techniques are being used: landfarming (1440 m^3), windrow composting soil piles (480 m^3) and static piles, fitted with enforced aeration system (240 m^3), Fig. 3 provides an outlay of the bioremediation system used. Four landfarming plots

40 m x 30 m each, were constructed of the processed soil to give 30 cm depth. The plots are tilled twice a week using agricultural rototiller and irrigated by a Pivot irrigation system to maintain sufficient water for optimum microbial activity. For the windrow composting piles eight soil piles were constructed, each pile is 3 m wide, 20 m in length and has a height of 1.5 m. The piles are fitted with leaky pipes to provide continuous supply of water for microbial growth and metabolic activities. Fig. 4 represents a cross section in the pile showing the arrangement of the leaky pipes. The piles are turned over once a month using front loaders for mixing and aeration. Four static soil piles were also constructed in a similar way, with the exception that the piles are fitted with perforated plastic pipes buried on the ground inside the piles, and connected to air compressors to provide sufficient oxygen for hydrocarbons biodegradation (Battaglia and Morgan, 1994). Composite soil samples are routinely collected from all the soil plots and piles for the analyses of petroleum hydrocarbon concentration and other key parameters. Certain landfarming plots and soil piles will be inoculated with hydrocarbon-utilizing microbial strains, which have been isolated in the laboratory. These strains have proven catabolic capabilities, particularly towards PAHs and heavy-molecular weight hydrocarbons. The soil bioremediation program has started on June 1st, 1995 and will continue until end of March, 1996.

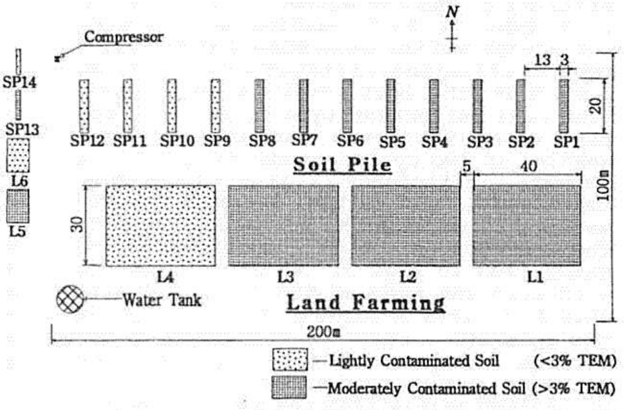

Fig.3 Layout of Bioremediation Systems

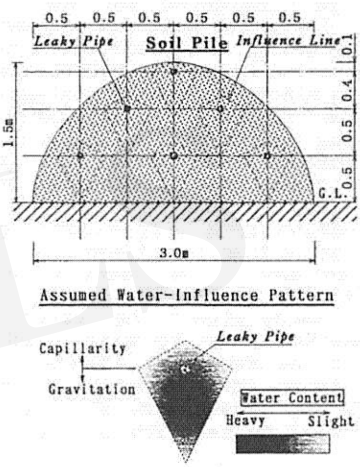

Fig.4 Cross Section with Soil000 Composting Pile

4. Physical/Chemical Treatment

For the treatment of the oily sludge and heavily contaminated soil, appropriate technologies were reviewed (Elnaggar et al 1991; Kostecki and Calabrese 1990), suitable washing processes were developed and their efficiencies were assessed in the laboratory. Series of a total 130 bench-scale experiments were conducted with kerosine, water and surfactant at elevated temperatures. The objectives of the experiments were to determine the oil removal rates achieved with the pre-determined variations and obtain the necessary data for the design of the pilot scale soil and oily sludge washing unit. The variations included: 1) washing with kerosine (10%, w/w); 2) washing with a mixture of water, surfactant and kerosine; 3) washing in two cycles involving solvent followed by water and surfactant. Three water ratios (50, 100 and 200 %, w/w) and four surfactant, designated A,B,C,K, at three concentrations (0.5, 1.0 and 2.0%, w/w) were tested. The tests were conducted at two temperatures 70°C and 90°C. The soil washing was conducted in two unit operational steps: (1) mixing of the sample with the washing agent for 15 min. and keeping the mixture at the experimental temperature for the determined contact time (10 min.) under continuous stirring; (2) separation of the treated soil from the washing agent and the oil phase by centrifugation (5 min. at 2000 rpm) at the experimental temperature. The results were then reviewed and further tests were conducted to improve the cost effectiveness of the process by the optimization of surfactant application. These experiments were conducted with lower surfactant concentrations (0.1, 0.2 and 0.5 %, w/w). The evaluation of the experimental results was carried out by visual inspection, measurement of recovered oil and residual oil in the washed soil/sludge measured as total extractable matter (TEM), presented as percentage of wet sample weight. For the experiments, heavy contaminated soil (16.3% TEM) and oily sludge (29.4% TEM) were used. The following is brief summary of the results: 1) Soil washing with kerosene resulted in up to 49.3%, removal efficiency and the washed soil contained 10 % TEM. 2) Soil washing with water, surfactant and kerosene showed up to 78.1 % removal efficiency, treated soil contained 3.6 - 5.8% TEM. Best results were obtained with 2.0% surfactant type C, at 70°C. The best water ratio was variable. 3) Soil washing in two cycles produced up to 87 % removal efficiency, treated sample contained 2.1 - 2.6% TEM. The best results were achieved with the surfactant type C. The results of best experiments are summarized in Fig. 5. 4) Sludge washing with kerosene reduced TEM from 29.4 % to 15.0 %, further washing with water reduced TEM to 6.3%.

The contaminated material contained elevated concentration of salt content originated mainly from the use of seawater to extinguish oil well fire. Salt content is an important factor, if the treated soil will be considered for any plantation. About 60% of the salt can be removed by the soil washing. In conclusion, the results demonstrated that the hydrocarbon content of the sludge and heavy contaminated soil can be reduced significantly by soil washing processes using kerosene, surfactants and water up to a level appropriate for biological treatment.

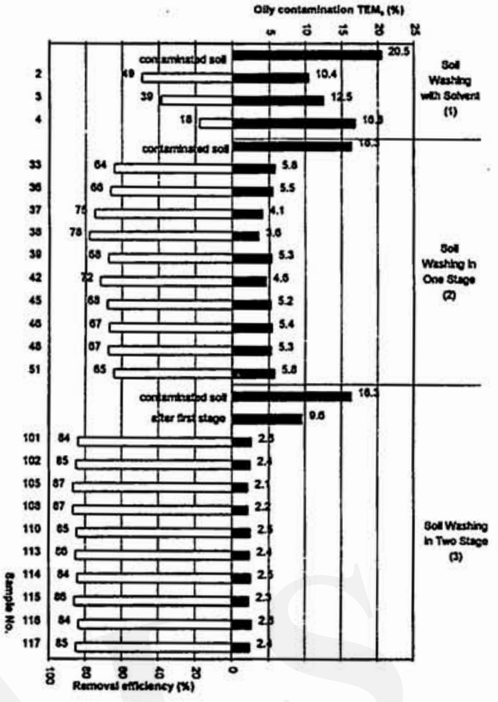

Fig.5 Efficiency of the Technological Variations

The recovery of significant oil percentage from oily sludge by kerosene washing is feasible, however, the recovery of kerosene for recycling requires additional unit operation. The solid phase needs also to be treated further in second stage by water washing for further reduction oil content prior to biological treatment. The economic aspects of the process, wastewater recycling /treatment and air emission control should be further studied before its large scale implementation. The removal of the remaining salt may be necessary if the soil will be used for greenery or agricultural purposes.

5. Conclusion

Substantial progress has been made in first year of the project, site investigation revealed for the first time important field data on the nature and distribution profile of contamination in the oil lake beds and the volumes of contaminated materials which require remediation. Biological treatment of the contaminated soil, using three techniques is being evaluated at a field scale. Appropriate processes have also been developed and assessed in the laboratory for the treatment of oil sludge.

Acknowledgement

The authors are grateful to KISR, PEC for the financial support and to the KOC for the cooperation and valuable contribution to the project. The authors would like also to acknowledge the kind efforts of the Ministry of Defence in clearing the site from the explosives and mines.

References

Al-Awadhi, N. M., Abdal, M. S., Briskey, E. J. and Kenneth, W. (1992): In Proceedings, 85th Annual Meeting and Exhibition, Kansas City, Missouri, (21-26 June.) p. 1-23.

Elnaggar, H., Bordelon, N. J. and Elnaggar, T. (1991): Proceedings, Third International Symposium on Industry and Environment in the Developing World, (Alexandria Egypt 27-29) May. p. 101-122.

Kostecki, P. T. and Calabrese, E. J. (1990): Petroleum Contaminated Soils. Chelsea, Michigan USA : Lewis Publishers, Inc:3 :368 -369.

Battaglia, A. and Morgan, D.J. (1994): Environ. Progress, 13: 178-187

Balba, M. T. (1993): In Exploitation of Microorganisms (ed. D.G. Jones), Chapman & Hall, London pp. 371-410.

Crops & bioremediation

C1: Chaired by J. Young & I. Endo
C2: Chaired by A. Richmond & M. Shiraishi

Contents

Invited Special Articles

Original Articles

沙漠研究 5S, 199-202(1995)
Journal of Arid Land Studies

Desert Biosystems

Amos Richmond*

Abstract - Arid land agriculture requires for its proper development unique, science-based strategies, based on wise utilization of solar energy. Two opposite approaches for desert biosystems are described; One involves super intense plant production in a closed system, eliminating water as a limiting factor for plant productivity, the other approach is based on growing microorganisms which thrive on saline water. Both systems produce very large yields per unit of enclosed area.

Key words: controlled greenhouse, radiation filter, saline water, microalgaculture, bioreactors.

1. Introduction

Arid land agriculture requires for its proper development unique strategies, fundamentally different from agriculture in the more humid, temperate regions. Science-based agriculture must be introduced in today's barren lands to unlock their full productive potential. In order to live, work and practice agriculture in the desert, man must learn to create unique microenvironments taking maximum advantage of the substantial, albeit few, favorable desert conditions. Benefiting from the extreme desert environment must be based primarily on wise utilization of solar radiation, converting the abundant "wasteful" flux of irradiance in the desert into economic opportunity. This paper describes and compares two opposite approaches: One aims at greatly enhancing plant productivity while very sharply curtailing water consumption, eliminating in effect fresh water as the growth-limiting factor in the desert. The other aims at exploiting intense radiation and locally available salty ground- or sea water, to grow microalgae for various economic purposes.

2. Controlled Greenhouse

2.1 The liquid radiation filter (LRF) Conventional greenhouses in warm lands have to be opened or actively cooled during the day to prevent over-heating. In winter these greenhouses have to be heated at night to prevent chilling. In an open greenhouse, transpiration is high and the plants require frequent watering to alleviate water stress. Closing the greenhouse creates a humid atmosphere, greatly reducing transpiration and net water consumption by the plants. The internal temperature in a closed greenhouse becomes usually much too high for plant growth, thus interception of the excess radiation in the greenhouse roof and walls is mandatory to prevent overheating. This task was undertaken by Joe Gale, heading a group of scientists and engineers, most prominent of whom has been S. Levi, M. Zeroni and R. Kopel (1991 a,b,c). This group developed a liquid radiation filter (LRF) with good radiation selectivity, as well as the components needed to construct and operate an LRF greenhouse.

2.2. The energy handling system is based on the LRF which absorbs and transports excess energy from the greenhouse (during sunny hours) and returns and distributes stored or otherwise available energy back to the greenhouse (during the night). The system is composed of two flow cycles (Fig, 1): the liquid radiation filter cycle and the sink-source cycle. The cycles are coupled by means of a heat exchanger. The first cycle uses the LRF as a working medium. Its components are: circulation pumps and controls; liquid radiation filter (LRF) panels and a heat exchanger. The second cycle uses water as a working medium, and it contains circulation pumps and controls a heat exchanger. In the Negev desert a water heat storage tank and a cooling tower are necessary. They would not be required wherever a source of cooling water were available for use in the heat exchanger.

2.3 The properties of LRF The LRF roof absorbs approximately 95% of the near infrared radiation which is not used by the plant and lets through about 85% of the photosynthetically active radiation. Thus, the heat load on the plant is reduced, almost by half. The LRF heats up as it

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flows in the roof and is cooled upon leaving it, in a heat exchanger. This energy is stored in a water reservoir for night use. The LRF further absorbs all the long wave radiation from within the greenhouse and from condensation and sensible heat. The temperature inside the greenhouse depends therefore on that of the LRF, which may be controlled by the speed of LRF flow. The greenhouse can be kept closed throughout the day at near optimum temperatures even in hot sunny climates. The greenhouse atmosphere may be enriched with CO_2, even at high radiation levels - a major factor for increasing growth and yields. Also, and no less important, water consumption by the plants in our LRF-controlled closed greenhouse is drastically curtailed, amounting to some 10% of the water required in the open field for comparable plants.

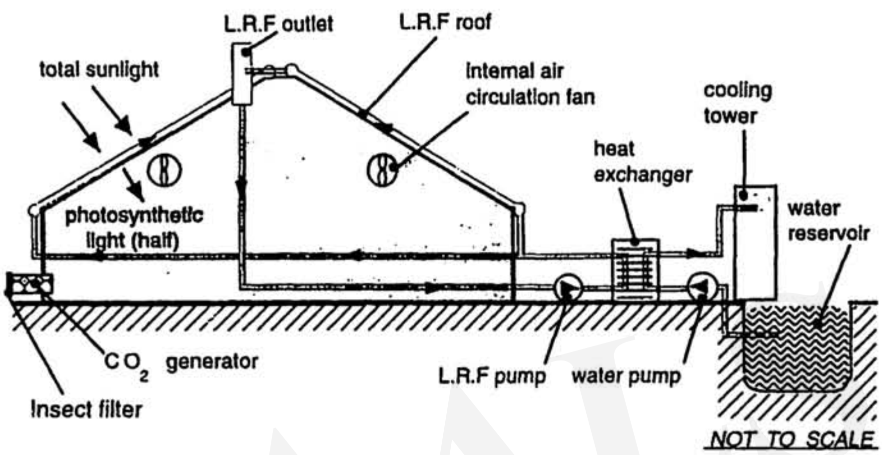

Fig. 1. General scheme of the liquid radiation filter (LRF) greenhouse. (Gale, Levi, Kopel & Zeroni, 1995)

The combination of controlled temperatures, filtered radiation, high humidity (without condensation on the leaves) and high ambient CO_2 throughout the day, has resulted in yields which are nearly always more than double those obtained in the best conventional Israeli greenhouses. Economic analysis, however, suggests a cost break-even requirement of only an extra 20-30% yield.

Five years of experience with a 330m^2 model of the LRF greenhouse at Sede Boker (by Gale, Levi, Kopel & Zeroni, 1995) show that (i) in this greenhouse very little supplementary night-time winter heating is required; (ii) the system can be kept closed throughout the day, apart from a few hours per day during hot weather; (iii) water use is very low,; (iv) leaf condensation does not occur and (v) insect entry is very much retarded.

3. Microalgalculture

3.1 General background This is an entirely new approach to agriculture in arid regions, which in common with the controlled environment greenhouse, is tuned to benefit from the unique desert environment. Algaculture concerns the culturing of microscopic algal cells in large ponds or reactors. It responds well to the high daily temperature and solar irradiance that abound the year round in the desert, as well as to the low night temperature. It utilizes local water resources e.g. - brackish, or sea water, to produce biomass for various economic purposes, covering a potentially very wide range of natural products, human food and animal feed.

The idea to grow microalgae as a source of biomass for various economic purposes originated some 70 years ago with the realization that certain algal species e.g. *Chlorella* proliferate very rapidly. Development of the biotechnology for mass production of microalgae began in Germany, the USA and Japan in the early 1950s. Special impetus to this idea was provided in the early 1970s by reports of an impending protein crisis which encouraged the introduction of single cell crops for human and animal consumption. In this framework, photoautotrophic microorganisms have been given special attention as a basic nutritious source which may be quickly produced for the rapidly expanding human population. Not only food, but essentially all organic products for human needs (except wood and fibers) may be produced from different species of microalgae. In most species, it is possible to enhance the production or the storage capacity of useful cell constituents, e.g. proteins, carbohydrates, fats, pigments, vitamins, alkaloids, antibiotics and drugs, by modifying the cell's environment or genetics.

3.2 Utilization of saline water for microalgaculture The fact that many species of microalgae can be cultivated in saline medium, i.e. brackish- or sea-water provides an important incentive to develop a microalgal industry in many lands rich in solar radiation where a shortage of sweet water for conventional agriculture is acute. As humanity in the arid and semi-arid regions expands, doubling or even tripling in size in the next generations, it will become of utmost importance to utilize marginal saline water for bio-production.

3.3 Utilization of open systems for microalgaculture The most common system presently employed by industry for growing microalgae is the open raceway. They usually cover an area of 1000 to 5000 m^2, lined with concrete or plastic sheets, employing a paddle wheel for stirring. Provided mineral and carbon nutrition are not growth-limiting, two major environmental factors control productivity in an open raceway i.e. - solar irradiance and temperature. Maximal utilization of solar energy may obviously be achieved only when the temperature is optimal for the species whereas the usual case for open systems is that temperature is not optimal. When day temperature falls significantly below the optimum for the species, irradiance may become severely harmful.

The many drawbacks of the open system have been presently recognized. One relates to the fact that open raceways require a minimal depth of 15 to 20 cm. This relatively long light path mandates low cell concentrations (e.g. - 500 $mg.l^{-1}$ of dry weight) resulting in a need to handle, at high expense, very large culture volumes (e.g. - 1500 m^3 of algal suspension per ha.). The low population density creates great difficulties in preventing contaminations. Thus only two species of microalgae are grown today commercially in open systems - *Dunaliella* and *Spirulina*, both requiring growth media high in salinity or alkalinity which impart in effect resistance to contaminating microorganisms. Other species of microalgae cannot be grown successfully in open systems, as they usually become contaminated in a short span. Daily evaporation rates from these shallow pans are very significant amounting to ca. 10% of their volume and requiring a constant addition of water, affecting salinization of the growth medium. Dilution by rain as well as easy access of airborne particles such as dust and organic debris create obvious difficulties. Finally, harvesting of the algae, i.e. removing the algal mass from the growth-medium, represents a significant expense in the cost of production, due to the necessity for handling very large volumes of culture suspension per unit harvestable product. Under the best circumstances and production methods (e.g. - Siam Algae, Bangkok), the average annual daily output is ca. 13 gm of dry weight per m^2, or ca. 0.1 gm. l^{-1}), some 10 to 20% of the theoretical potential. The high cost of production, coupled with the limited choice of species suitable for this production system, makes it clear that the open raceway represents in effect an 'end of the road' of microalgaculture. Were these systems to remain the major production modes available for mass cultivation of photoautotrophs, this promising biotechnology would quickly reach its limits.

3.4 Enclosed reactors The severe limitations of the open systems for mass production of microalgae prompted interest in enclosed reactors, sealed from direct exposure to the atmosphere (Richmond 1993). Enclosed reactors have many advantages over open systems: having a small (e.g. 1.0 to 5.0 cm) light path and a very large surface to volume ratio, these reactors facilitate ultra high cell concentrations (e.g. 5 to 15 gm dry weight per liter). Such high cell densities greatly reduce the cost of harvesting and facilitate maintenance of monoalgal cultures, absolutely mandatory in industrial production. Also, closed systems permit a better and more efficient mode of CO_2 distribution and most important - facilitate easy temperature control during day-light as well as preventing evaporation losses from the algal suspension. Finally, the great promise enclosed photobioreactors hold over open systems concerns the very significant increase in volumetric productivity facilitated by the narrow light path. Thus an average daily productivity of *Spirulina* in an open raceway is 0.2 gm. dry weight per liter day^{-1}, whereas the daily yield of this alga in a 2.5 cm bore tubular reactor could amount to ca. 1.5 gm per liter. Closed systems require ca. 10% of the area taken by open systems and ca. 15% of their volume. These factors should result in the long run in a meaningful reduction of production cost.

The hope for developing microalgaculture into an industrial entity rests accordingly in developing efficient i.e. cost effective photobioreactors which would facilitate greatly increased volumetric productivity and result in a decreased costs of production. It is my belief that once an efficient photobioreactor is developed, microalgaculture will rapidly expand into a growing and prosperous industry.

3.5 Description of the newly designed flat, inclined modular photobioreactor The vast potential of a well designed photobiorector of mass cultivation of *Spirulina platensis* outdoors may be observed in the work of Hu Qiang and Richmond (1995), developing a new photobiorector which consists of a series of individual glass reactors measuring 70 cm high, 90 cm long and 2.6 or 1.3 cm wide (Fig. 2). The reactors are facing south with inclinations of 30° and 60° for summer and winter, respectively, and are connected by tubing in cascade. The air-bubble mixing system creates very intensive and systematic circulation in each single reactor. (e.g. 2.5 liter air per liter algal suspension). Recycling the algal suspension in the entire system is carried out by an air lift connecting the end reactors in the cascade. Temperature is controlled by evaporative cooling, supplied by water sprinklers. Record output rates of algal mass (e.g. - 60 gm dry weight per m^2 d^{-1} of *Spirulina*) have been obtained with steady state cell concentrations of 6 to 10 gm. l^{-1}.

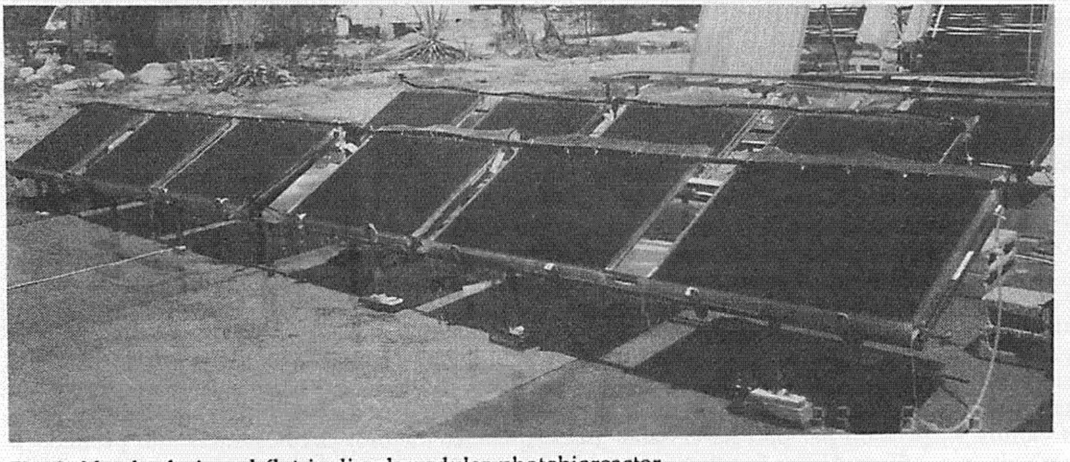

Fig. 2: Newly designed flat inclined modular photobioreactor

4. Conclusions

Both of the biosystems described i.e. - a novel liquid radiation filter greenhouse and an enclosed photobioreactor for mass production of microalgae - may support very high rates of bioproductivity in the desert, based on abundant, locally available resources.

References

Gale, J., S. Levi, R. Kopel and M. Zeroni. Controlled Environment Desert Agriculture pp. 207-216. In: Scientific Activities 1993-1994. Published by the Jacob Blaustein Institute for Desert Research, Sede Boker, 84990, Israel.

Hu, Q. and A. Richmond. Microalgal Biotechnology pp. 219-240 in Scientific Activities 1993-1994. Publication by the Jacob Blaustein Institute for Desert Research, Sede Boker, 84990, Israel.

Kopel, R., J. Gale, M. Zeroni and S. Levi. A greenhouse with selective radiation filtering under desert conditions. Proc. of the Int'l Symp. Applied Technology of Greenhouses, L. Buzhou (Ed.), CSAE, Knowledge Publishing House, Beijing, China. pp. 63-68 (1991 a)

Levi, S., M. Zeroni, J. Gale and R. Kopel. Development of liquid radiation filters for use in greenhouse. *ibid*, pp. 69-73 (1991 b)

Richmond A. (1993) Mass Production of Microalgae: a Mode of Industrial Photosynthesis. In: Trends in Photosynthesis Research. Barber, J., Guerrero, M.G. and Medarano, H., Eds., Intercept Andover, Hamshire.

Zeroni, M., J. Gale, R. Kopel and S. Levi. Agrotechniques for a closed greenhouse with a radiation roof. ibid, pp. 57-62, (1991c).

沙漠研究 5S, 203-206(1995)
Journal of Arid Land Studies

Guayule Natural Rubber:
A Promising Source of Latex for Medical Products

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Abstract - Recent findings show that latex rubber from guayule (*Parthenium argentatum*), a desert-adapted shrub, is hypoallergenic. Thus, this latex has great promise as a renewable raw material in the medical products market to replace allergy causing latex. Guayule rubber particles are formed and remain in the individual cells so latex extraction from guayule requires different procedures than from the Brazilian rubber tree (*Hevea brasiliensis*). Our presentation covers the technological development needed to extract the latex, the properties of the latex, and the cultivation of the shrub for commercialization.

Key words: Guayule, Latex, Rubber, Allergy, Resin

1. Introduction

Rubber products made from the Brazilian rubber tree (*Hevea brasiliensis*) are known to cause allergic reactions in humans ranging from irritating skin rashes to life-threatening anaphylactic shock. The U.S. Food and Drug Administration has issued warnings concerning the allergic responses of subjects exposed to *Hevea* latex items (Tomazic *et al.*, 1992). International conferences *e.g.* (Crain Communications, 1993; International Latex Conference, 1992) have been conducted on the nature, cause, and control of the *Hevea*-caused allergies.

The discovery that the latex rubber from the guayule plant is hypoallergenic has created great interest in making medical products from this latex. A patent (Cornish, 1995) has been applied for making products from the guayule latex, whose protein and resin composition are significantly different than *Hevea* latex. The hypoallergenic property of guayule latex has tremendous implications for the actual commercialization of this crop (Wright *et al.*, 1991). Commercialization in the past has not been successful because *Hevea* rubber is cheaper to produce than guayule rubber. The rubber from guayule has the same chemical composition (*cis*-1,4-polyisoprene) as *Hevea* and, when properly processed, similar physical properties. Rubber from guayule has already been demonstrated to be equivalent to *Hevea* rubber for use in aircraft and automobile tires.

Historically, in the early 1900's, automobile tires in North America were manufactured from guayule rubber (Hammond and Polhamus, 1965). Guayule shrubs were harvested from wild stands in northern Mexico. The relocation of *Hevea* natural rubber production to southeast Asia, accompanied by increased latex yields, lower production costs, and improved marketing, virtually eliminated guayule as a competitor. The United States made a major effort in the early 1940's to produce guayule rubber to replace *Hevea* rubber, which became unavailable during World War II. However, with the return of sufficient supplies of *Hevea* rubber, interest in guayule greatly diminished. The petroleum crisis of the 1970's refocused attention on guayule rubber. The price of natural rubber increased rapidly and also there was a prediction that a natural rubber shortage was to occur in the 21st century. Thus, during this period, research and development activities were increased in the United States and a prototype facility for solvent extraction of rubber from capacity to handle 10 tonnes of shrub per day. In addition, several hundred hectares of guayule

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shrubs were planted to supply the extraction facility. The processing plant has been deactivated, but the rubber produced from it has been used to manufacture truck and aircraft tires, which are now undergoing vigorous testing.

The economics for establishing a viable guayule market depend upon the price of *Hevea* rubber and yield of guayule. The price of *Hevea* rubber has increased to about $2.20 per kg bulk or solid rubber in 1994, which is about the break-even point for guayule commercialization (Wright *et al.*, 1991). The preceding model was based on the production of "solid" or "bulk" rubber for tire manufacturing. Also, doubling guayule rubber yield from 560 to 1,120 kg/ha, which is believed to be achievable through germplasm improvement, would greatly enhance the economic structure for guayule rubber production. Furthermore, latex rubber commands a premium price of about $4.00 per kg and promises a much better economic return than bulk rubber. In addition, the manufacture of hypoallergenic medical devices from guayule latex would substantially increase the value of the raw material. In the United States, guayule can be grown on land that is presently going out of production or has been set aside for various economic and environmental reasons. *Hevea* latex production has always been labor-intensive, and the cost of labor continues to increase. Guayule production, on the other hand, can be almost completely mechanized using existing field equipment with minor modification.

2. Guayule Latex

Guayule rubber particles are formed in individual cells and reside there permanently instead of being transported within the plant (National Academy Sciences, 1977). Detailed studies of guayule rubber particles have been made to ascertain the factors responsible for rubber synthesis (Backhaus, 1985; Benedict, 1982; Cornish and Backhaus, 1990). By the early 1990's, allergic reactions to *Hevea* latex were becoming more prevalent and the non-*Hevea* rubber synthesis work naturally led investigators to look into the allergy problem and the proteins involved in allergy sensitization. Antibody reactions were negative for the guayule latex, but positive for *Hevea* latex and film extracts (Siler and Cornish, 1995). Preliminary clinical studies show that individuals hypersensitive to *Hevea* latex had no reaction to guayule latex, but reacted strongly to *Hevea* (Carey et al., 1995). In the United States, approximately 20 million persons are estimated to be allergic to *Hevea* latex products, a major proportion of these being medical workers (Cornish and Siler, 1994). A large potential market exists for hypoallergenic guayule latex medical products for the allergic and even the nonallergic population. Before commercialization can occur, a reliable source of guayule latex must be available.

3. Guayule latex extraction

Since the guayule rubber particles remain in the parenchyma cells after synthesis, their removal must be through maceration of the plant. Jones (1948) extracted crude latex by grinding the guayule shrub in a water medium and concentrating the latex by centrifugation. There was no interest in the latex as such, so the latex was converted to solid or bulk rubber by coagulation. In fact, the flotation method was the primary system for obtaining bulk rubber (Byrne, 1975). The guayule rubber contained 20 to 25% resinous materials and their removal was necessary to improve the physical properties of the rubber (Taylor, 1975). Recent studies have shown that the shrub must be "fresh" or processed as soon as possible after harvest to prevent latex yield decreases (Nakayama and Coates, 1995). Drying of the shrub greatly decreases latex extractability, and treatments such as air-drying, freeze-thawing, and parboiling can reduce latex yields to nearly zero.

Present work on latex extraction is based on the procedure used for preparation of the rubber particles with active rubber transferase enzyme from guayule (Cornish and Backhaus, 1991). Only a solution containing an anti-oxidant (Na_2SO_3) and polyvinylpolypyrrolidone (PVPP) is used in the grinding of the shrub. The crude latex is stabilized with ammonium hydroxide to pH 10 and concentrated by centrifugation. The latex, washed by several centrifuging and creaming operations, contains about 6% resin and has a Mooney viscosity of about 60% of the *Hevea* latex. Water soluble impurities can be removed by washing, but the resin intimately associated with the rubber particles must be removed by solid phase extraction or a mixture of water soluble organics that will not coagulate the latex. This aspect of purification is still under investigation.

4. Guayule Resin

Guayule resin is synthesized in the epithelial cells and secreted into the duct lumen (Joseph *et al.*, 1988). Most of our understanding of the resinous materials and their composition is based on solvent extraction (pentane, hexane, methanol, acetone, furan, and mixtures) of the guayule shrub. The resin has a degradative effect on solvent-extracted bulk rubber (Keller *et al.*, 1981). A large variety of compounds have been identified in the extracts including flavonoids, terpenes, sesquiterpenes, sesquiterpene esters, fatty acid triglycerides, and polysaccharides. (Banigan *et al.*, 1982, Kumamoto *et al.*, 1985; Schloman *et al.*, 1988; Schloman *et al.*, 1991). One of the fatty acids, linoleic acid, appears to be the cause of the degradation of bulk rubber. Since most of these resinous materials are not water soluble, they should not create a processing problem, unless they are bound to the rubber particles.

The resin itself has potential as a plasticizer modifier in epoxy resin coatings (Thames and Kaleem, 1991). Wood impregnated with the resin was found to be resistant to a variety of wood-damaging insects, including termites, and some species of fungi and molluscan borers (Bultman, *et al.*, 1991). Chemical derivatives of resin and resin fractions were shown to improve the properties of rubber compositions (Schloman, 1988). The value of the resin coproducts could be significant.

5. Guayule cultivation

Guayule cultivation has never been done on a large and continuous scale. Information on its culture has developed through the years and the last major research studies of the 1980's have been compiled by Whitworth and Whitehead (1991). Guayule is drought tolerant and can be grown under dryland conditions of 300-600 mm rainfall per year in coastal areas to 1,500 mm in arid regions with supplemental irrigation (Nakayama *et al.*, 1991). Rubber yields can be greatly enhanced by additional water applications and water regulation is possibly the best management tool for optimizing shrub and rubber production (Nakayama, 1991). Farming operations from planting, cultivation, to seed and shrub harvesting have been essentially mechanized using existing equipment with minor modifications (Coates, 1991).

Bulk rubber yields have almost doubled through germplasm improvement of the older guayule lines (Estilai and Ray, 1991). The question remains, however, whether the latex yield is equivalent to solid rubber yield. Other factors relating to latex yield are the age of the plant and season of harvest, since rubber synthesis is also related to these factors (Backhaus, 1985; Benedict, 1982). Answers to some of these unknowns must be obtained as the research on agronomic development progresses.

6. Summary

Much of the latex production research is in the developmental state at present. Except for the agronomic studies that are being conducted in field plots, the latex work is laboratory oriented. There appears to be little problem in the scale-up of latex production to meet industrial requirements. However, all of the various factors from agronomic practices to latex extraction and fabrication must be coordinated and vertically integrated to achieve rapid commercialization.

Since latex extraction is water-based, large volumes of water will be required and this may be a premium in the semiarid to arid regions where guayule is expected to be cultivated. However, much of the water used in the extraction process can be recycled.

References

Backhaus, R.A. (1985): Israel Journal of Botany, 34: 283-293.
Banigan, T.F., Verbiscar, A.J. and Weber, C.W. (1982): Journal of Agricultural Food Chemistry, 30: 427-431.
Benedict, C.R. (1982): In J.W. Porter and S.L. Spurgeon (Eds.). Biosynthesis of Isoprenoid Compounds. Vol. 2, John Wiley, N.Y. pp. 355-369.
Bultman, J.D., Gilbertson, R.L., Adaskaveg, J., Amburgey, T.L., Parikh, V. and Bailey, C.A. (1991): Bioresource Technology, 35: 197-201.
Byrne, J.J. (1975): In W.G. McGinnies and E.F. Haase (Eds.). Proc. Intern. Conf. Utilization of Guayule. University of Arizona, pp. 41-51.
Carey, A.B., Cornish, K., Schrank, P.J., Ward, B. and Simon, R.A. (1995): Annals of Allergy, Asthma and Immunology, 74: 317-320.
Coates, W. (1991): In J.W. Whitworth and E.E. Whitehead (Eds.). Guayule Natural Rubber. USDA, CSRS, OALS. Tucson, AZ. pp. 241-259.
Cornish, K. (1995): U.S. Patent Office, Pending Patent Application 08/4423,911.
Cornish, K and Siler, D.J. (1994): Proc. Intern. Conf. Assoc. for the Advancement of Industrial Crops. (In Press).
Crain Communications, Ltd. (1993): Latex Protein Allergy: The Present Position. Crain Communications, Ltd., Rubber Consultants, Hertford, United Kingdom.
Estilai, A. and Ray, D.T. (1991): In J.W. Whitworth and E.E. Whitehead (Eds.). Guayule Natural Rubber. USDA, CSRS, Office of Arid Lands Studies, University of Arizona, Tucson, AZ. pp. 47-91.
Hammond, B.L. and Polhamus, L.G. (1965): Research on Guayule (*Parthenium argentatum*): 1942-1959. USDA Tech. Bull. No. 1327. U.S. Printing Office, Washington, D.C.
International Latex Conference. (1992): Sensitivity to Latex in Medical Devices. Food and Drug Administration, Baltimore, MD, USA.
Joseph, J.P., Shah, J.J. and Inamdar, J.A. (1988): Annals of Botany, 61: 377-387.
Keller, R.W., Winkler, D.S. and Stephens, H.L. (1981): Rubber Chemistry and Technology, 54: 115-118.
Kumamoto, J., Scora, R.W. and Clerx, W.A. (1985): Journal of Agricultural and Food Chemistry, 33: 650-652.
Milthorpe, P., Paterson-Jones, J.C., Whitworth, J.W., Abel, G. and Miller, W.P. (1991): In J.W. Whitworth and E.E. Whitehead (Eds.). Guayule Natural Rubber. USDA, CSRS, OALS. Tucson, AZ. pp. 367-421.
Nakayama, F.S. (1991): In J.W. Whitworth and E.E. Whitehead (Eds.). Guayule Natural Rubber. USDA, CSRS, OALS. Tucson, AZ. pp. 217-240.
Nakayama, F.S., Bucks, D.A., Gonzalez, C.L. and Foster, M.A. (1991): In J.W. Whitworth and E.E. Whitehead (Eds.). Guayule Natural Rubber. USDA, CSRS, OALS. Tucson, AZ. pp. 145-172.
Nakayama, F.S. and Coates, W. (1995): Proc. Intern. Conf. Assoc. Advancement of Industrial Crops. (In press).
National Academy of Sciences. (1977): Guayule: An Alternative Source of Natural Rubber. NAS, Wash., D.C. 80 pp.
Schloman, W.W., Jr. (1988): Industrial and Engineering Chemistry Research, 27: 712-716.
Schloman, W.W., Jr., Carlson, D.W. and Hilton, A.S. (1988): Biomass, 17: 239-249.
Schloman, W.W., Jr., McGrady, J.J. and Hilton A.S. (1991): Bioresource Technology, 35: 191-196.
Schloman, W.W., Jr., Hively, R.A., Krishen, A. and Andrews, M.A. (1983): Journal Agricultural and Food Chemistry, 31: 973-976.
Siler, D.J. and Cornish, K. (1994): Industrial Crops and Products, 2: 307-313.
Taylor, E.C. (1975): In W.G. McGinnies and E.F. Haase (Eds.). Proc. Intern. Conf. Utilization of Guayule. University of Arizona, pp. 41-51.
Thames, S.F. and Kaleem, K. (1991): Bioresource Technology, 35: 185-190.
Tomazic, V.J., Withrow, T.J., Fisher, B.R. and Dillard, S.F. (1992): Clinical Immunology and Immunopathology, 64: 89-97.
Whitworth, J.W. and Whitehead, E.E. (1991): Guayule Natural Rubber. USDA, CSRS, OALS. Tucson, AZ.
Wright, G.N., Fansler, S. and Lacewell, R.D. (1991): In J.W. Whitworth and E.E. Whitehead (Eds.). Guayule Natural Rubber. USDA, CSRS, OALS. Tucson, AZ. pp. 351-365.

沙漠研究 5S, 207-210(1995)
Journal of Arid Land Studies

Technology for Desert Aquaculture

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Abstract - The existence of large quantities of brackish, geothermal water under the Israeli Negev Desert made it possible to develop desert aquaculture in Israel. A few years after the beginning of initial research, several Israeli farmers have reached the stage of commercial production. As production and operation prove to be successful, it is expected that in the near future, many more similar operations will be established, to create a major source of pollutant-free, high-quality fish for the local and export markets. Suitable technologies are under development to allow intensification of production, whilst ensuring preservation of the environment. It is obvious that the desert provides advantageous conditions for warm-water fish, compared with other regions in Israel.

Key words: aquaculture, brackish geothermal water, desert, technology.

1. Introduction

Under the surface of the Ramat Negev district of the Israeli desert (highlands of the Negev desert) are large quantities of brackish geothermal water, originating from two aquifers: 1 - the Cenomanian Turonian Aquifer; 2 - the Nubian Sandstone Aquifer. The first one consists of a sweet water body (Yarkon/Tananim) that extends from the north, down the Beer Sheva. Attached to it is a brackish water body which continues south from Beer Sheva into Sinai. While the fresh water aquifer is a naturally refilled one, the brackish one has minimal refilling. The salinity of the brackish aquifer increases towards its southern part. In the Rivivim, Mashabe Sade area, the salinity is approximately 1000 mg Cl/L; in the area of Nitzana it reaches 2000 mg Cl/L. The Nubian Sandstone aquifer of the lower Cretaceous era, lies below the first and is the largest aquifer in the Negev, reaching the Arava Valley and Sinai, but is not refilled. The salinity of this aquifer, in the area of Ramat Negev, is estimated to range from 1200 and 2200 mg Cl/L (at a depth of 1000 m). At present, there is no functioning well at Ramat Negev from this aquifer, but there are a few operational wells supplying water from the Cenomanian-Turonian aquifer.

Table 1. Brackish geothermal water in use in the Ramat Negev district of Israel

Name of Well	Date of Drilling	Depth (metres)	Salinity mg Cl/L	TDS	Flow-rate m^3/h	Temp (°C)
Mashabe Sade 1	1955-6	550	926	2680	270	39°
Mashabe Sade 2	1977-8	625	-	-	102-215	-
Rivivim 2	1974-5	914	1152	2710	320	41°
Nitzana	1982	732	1995	4366	350	39°
Ashalim 2	1978-9	914	1582	3722	250	33°

Brackish geothermal water from the Cenomanian-Turonian aquifer is in use in three areas of Ramat Negev:

Mashabe Sade, Rivivim: with approx. 2700 TDS; temperature - 39-41°C; flow rate - 600 m^3/h.
Ashalim : 3722 TDS; temperature - 33°C; flow rate - 160 m^3/h.
Nitzana: 4366 TDS; temperature - 39°C; flow rate - 3650 m^3/h.

For the past 25-30 years, brackish water has been used for irrigation of agricultural crops. With little initial scientific guidance, the encouraging results achieved stimulated and enhanced research work and cooperation between scientists and farmers. Today, desert agriculture in Israel, based on the use of brackish water, is modern, sophisticated, profitable and provides products for the local market, and for export at premium prices, eg, sweet tomatoes, melons, hay and recently olives for oil and grapes for wine.

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2. Desert Aquaculture in Israel

The history of desert aquaculture in Ramat Negev district started in the mid-80s when a joint research venture between the Aquaculture Unit of the Jacob Blaustein Institute for Desert Research in Sede Boker and the Research and Development Division of the District Council of Ramat Negev examined the suitability of the local brackish geothermal water for fish rearing. The experiments were carried out with eels, Tilapia, carp and catfish. The study found that the tested water: had no negative effect on the growth and development of the fish; no harmful effects on the fish body; no detrimental effect on the culinary quality of the fish; and that fish suffered less from parasites in brackish water than in fresh-water.

Today, desert aquaculture on a commercial scale exists in the Ramat Negev District. There is a dynamic among the local settlers and external investors for accelerating the development of this industry. It is expected that within a few years, the Israeli desert will provide significant quantities of edible and ornamental fish, produced in modern, intensive but environment preserving technologies, for the local and export markets. In addition to fish production, fish processing plants will be established so that the 'Desert Fish' will be marketed as a highly priced, gourmet item.

To the best of our knowledge, with the exception of an operation using well-water in the Californian desert, Israel is the only country with desert aquaculture using brackish geothermal desert water. It is obvious that this innovation will soon be adopted by other countries with similar conditions.

2.1. Benefits of the use of Desert Water in Israel: .

2.1.1. Objective advantages:

(a) Israel suffers a chronic fresh-water shortage.
(b) A large reservoir of brackish geothermal water - **the desert water** lies below the Negev Desert.
(c) **Desert water**, by its own force, reaches a level of approx. 20 m above MSL, and from there it has to be pumped to the surface.
(d) The present cost of **desert water** is lower than that of fresh-water which has to be pumped from the Sea of Galilee.
(e) The usage of **desert water** is vital to avoid salination of the fresh-water reservoir attached to it. The more fresh-water is used in the area of Beer Sheve, (the Negev capital), the more brackish water has to be pumped to avoid this risk.
(f) **Desert water** is already is use for agricultural irrigation, however to a limited extent only, as some crops cannot withstand its salinity.
(g) Proper use of **desert water** for irrigation should not cause salination of the soil as the local groundwater is deep.
(h) In the Negev, unlike other regions, land is still available.
(i) There is no strong competition in the country for **desert water**, as there is for fresh-water.
(j). The effluent and excess of fish growing water must not be returned to the fresh-water aquifer but can be used for irrigation.

2.1.2. Subjective advantages for desert aquaculture:

(a) The saline **desert water** provides an osmoregulatory advantage for the fish and is more detrimental to fish parasites.
(b) The constantly warm **desert water** accelerates fish growth throughout the entire period.
(c) **Desert water** is free of any industrial, household pollutants etc., and therefore guarantees a high quality fish product.

2.2. Technology for Desert Aquaculture - Typical desert characteristics are :

(a) extreme differences in air temperatures between day and night, summer and winter.
(b) low air humidity;
(c) strong winds with high dust deposits;
(d) low precipitation concentrated, in the short winter season;
(e) intense sun radiation during most of the year;
(f) desert geothermal water reaching the surface is of a higher temperature than can be tolerated by fish.

So far, there are two principal technologies in use for growing warm-water fish in desert conditions which maximize its characteristics .

2.2.1.Multiple User : In this technology geothermal well-water at 40ºC first passes into greenhouses for agricultural crops, in order to warm them to 25ºC during the winter by means of pipes either under or on the surface. This water then leaves the greenhouse at the reduced temperature of 28ºC, which is more suitable for the fish, and runs into the growing containers. From there, it enters sedimentation tanks to allow removal of floating particles. After separation, the water, rich in dissolved minerals, enters the irrigation system to field crops, orchards and public gardens.

This is an open system technology. Here the suspended material and toxic chemicals excreted by the fish are removed from the water by continuous flushing with new water entering the system. The amount of new water can reach 50% or more of the total system volume daily. This system, for which the capital investment is relatively low, allows the cost to be divided between the users. The disadvantages are: (a) water usage for the fish is dependent on last user; (b) necessity of creating a large operating water reservoir to collect the effluent from the fish system for balancing the water usage for other users ; and (c) inconsistent water quality when less water has to be used (ie, extremely hot days).

2.2.2.Recirculation system : In this system, the water leaves the growing unit, passes through a filtering purification section, to be returned to the fish. The heart of the system is the filtering and water purification parts, the efficiency of which determine the reduction in use of new water. Efficient water purification allows a minimum amount of new water to be introduced, i.e. 5% of the total system volume daily. This daily replacement makes up for losses caused by sludge discharge and evaporation, and permits minimal renewal. The high investment in water purification makes the recirculation system expensive, but the advantages are: (a) autonomous system; (b) easier to maintain physical and chemical water quality; and (c) efficient use of water resources.

A combination of the two principal technologies provides a number of variations. For instance, the culture of fish in combination with hydroponics where advantage is taken of the plants' ability to take-up and utilize nitrogen from the water. In this case, the plants act as water purifiers. However, suspended material still has to be removed from the water.

The common features of the two principal technologies (above), which characterize fish growing in deserts are:-

(a) very high stocking density (biomass) and intensive fish production;
(b) use of intensive culture, which facilitates the production of fish in much smaller water bodies than by conventional growing methods;
(c) enclosing and covering of the system which maximizes the control of water quality and the fish. This also reduces the intense solar radiation that enhances algae production, which compete with fish for the oxygen in the water. Lastly it also prevents dust sedimentation;
(d) use of geothermal desert water which allows maintenance of the desired water temperature without extra heating. The system is cooled during hot days by intense evaporation of the water using the extremely low humidity of the desert air.

2.2.3. Polyculture: In conventional polyculture, which is used in extensive fish farms, several different species are kept in the same water body. In intensive fish production, future polyculture should be designed in order that different fish species can be cultured in the same system, but in separate tanks with the water running in series from one to the other, and where each species benefits from the other. The first, primary, species in the chain, i.e., a carnivorous one, is supplied with protein-rich feed. The second species feeds on the residue and waste of the first, by filtering the water which it receives from the first fish. The third is an omnivorous fish, feeding on the organic material in the water received from the second fish. The stocking rate of the fish in the chain is determined by the biomass and feeding of the primary fish. Such polyculture could consist of eels as a primary fish, tilapia as the secondary and catfish as the third in the chain.

2.3. Accessory Techniques: As a result of the heavy density of fish in the growing system - for Tilapia approx. 25 kg m^3; for eels approx. 150 kg m^3; for catfish approx. 250 kg m^3; the biological load is very high. In order to minimize the water pollution, feeding techniques have been developed allowing the grower or the fish to determine the food portion more exactly (Fig. 1). For further reduction of water pollution, food is to be provided to the fish in a separate compartment within the growing system. The fish can easily enter the feeding compartment where the water is more heavily polluted because of feeding. After feeding, the fish returns to the growing tank where the water is significantly less polluted. A separate installation discharges the heavily polluted water from the feeding compartment (Fig. 2).

The following figure demonstrates the suitability of desert aquaculture to Israel. Tilapia, a warm-water, well accepted fish in many countries with a world production of 300,000 tons a year, is also produced in Israel. 40% of the total fish produced in Israel, mostly on kibbutz farms (equal to 5631 tons annually), is of Tilapia. From 1985 to date, there has been an increase in production. In 1992, a strong, cold winter caused heavy Tilapia mortalities all over the country, resulting in a decrease of 1400 (or 25%) tons. Recovery to the prior 1992 figure was achieved only in 1994. We believe that such a catastrophic phenomenon, in terms of mortalities or slow-down in growth because of cold, should never occur in desert aquaculture.

3. Conclusions

(a) Enormous quantities of subsurface geothermal brackish water are present in the Negev Desert of Israel.

(b) Because of its availability, warmth, salinity and purity, independent of external conditions, it is useful and most advantageous for aquaculture of warm-water fish.

(c) As Israel suffers a chronic fresh-water shortage, and extensive use of the fresh-water aquifer resting next to the brackish water aquifer risks the salination of the fresh-water, a balanced use of the brackish water is vital.

(d) After initial investigation at the Institute for Desert Research, farmers are now successfully producing fish in the Ramat Negev district.

(e) Technologies are under development to allow intensification whilst preserving the environment.

(f) It is expected that in addition to the growing number of fish farms in the desert, fish processing and transportation facilities will shortly be established to facilitate local and export marketing.

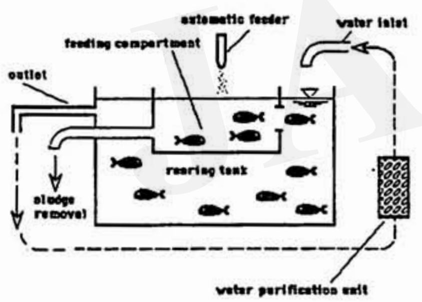
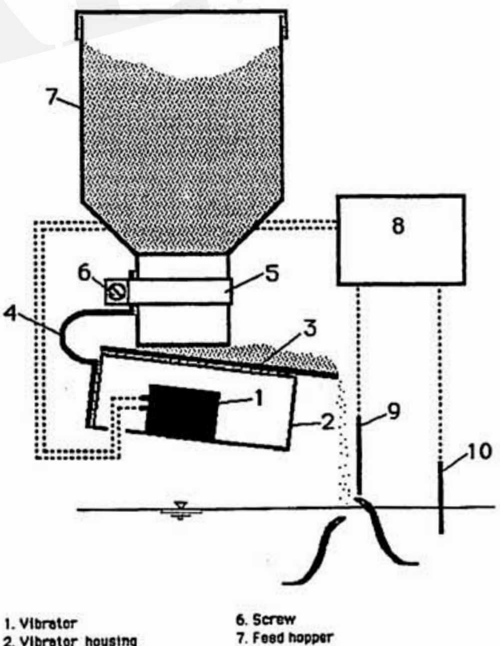


Fig.1. Scheme of the technology for feeding fish at high density



1. Vibrator
2. Vibrator housing
3. Feed table
4. Spring
5. Clamp
6. Screw
7. Feed hopper
8. Control unit
9. Upper electrode
10. Submerged electrode

Fig.2. A self-demand vibrofeeder for fish

沙漠研究 5S, 211-214(1995)
Journal of Arid Land Studies

Bioremediation of Polluted Soils in Arid Zones

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Abstract - In arid zones all bacterial metabolic activities are restricted to the time and place where sufficient matrix water is available. As a result we find that in the desert contaminants which are easily biodegradable elsewhere accumulate due to lack of available water. Therefore, the limitations imposed on microbial metabolic activities by the scarcity of matrix water make the desert a much more vulnerable environment than moist lands to pollution due to anthropogenic activities, even by otherwise biodegradable compounds, and not necessarily by recalcitrant chemicals.

Key Words: Organic & Inorganic Contaminants,Ochre, Nitrates.

1. Introduction

Soil bioremediation is an anthropocentric definition for the utilization by bacteria of various toxic organic and inorganic compounds to their own benefit, either as nutrients, energy sources, or sinks for disposal of reducing power. Incomplete degradation, or partial transformation of toxic molecules often results in the accumulation of toxic end products. An arid environment imposes severe limitations on these activities.

2. Water

Life requires available free water, and bacteria are no exception. In dry soils, water stress is the dominant factor which regulates all microbial activities. Free water availability is influenced in the soil by many factors, and these in turn might affect differently the various types of bacteria present in the soil. The amount of available water in the soil (water potential) is determined by their matrix potential (affected by adsorption and capillary effects of the soil composition and structure) and their osmotic potential which is determined by presence of solutes.

In the desert, all bacterial metabolic activities are restricted to the time and the place when and where sufficient matrix water is available, whereas the activity of the water will determine whether regular heterotrophs or halotolerant or halophilic bacteria will develop within a specific site. As a result we find that in the desert contaminants which are easily biodegradable elsewhere accumulate due to lack of available water. Therefore, the limitations posed on microbial metabolic activities by the scarcity of matrix water make the desert much more vulnerable than moist lands to pollution due to anthropogenic activities, even by otherwise biodegradable compounds and not necessarily by

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recalcitrant chemicals. One would also expect that natural microbial biodegradative activities during wet seasons will be limited to what can be achieved by a population of mainly gram positive spore formers, as these have the highest chances for survival during the dry seasons.From the point of view of biodegradation, the soil serves as a matrix which holds the bacteria, the pollutants, and the water. In the soil, water makes the contact between the bacteria and their target substrate. In this respect, dry soil in arid zones is no different than wet soil in a wet region. However, beside these considerations, it should be realized that an arid zone is not just an area which simply has less rainfall, where "everything is essentially the same but little less". The issue of bioremediation of soil in the desert is not a matter of simply adding water. Arid zone means a different life style, and specific adaptations to climate and environment. Life in arid zones is affected by many interacting factors, and because of these soil contamination and bioremediation frequently have in the desert different connotations and meanings than in wet regions.In Israel we came across several pollution problems which are a direct and specific result of human life and activities in the desert.

3. Agriculture:

Agriculture in arid zones often means irrigation is with recycled waste water , and this generates a whole set of problems such as salinization of the soil, due to the fact that each passage of the water through the municipal water system increases their salinity by about 100 mg/l, contamination of the soil with metals which are abundant in the effluents, and contamination of ground water with nitrates which originate from nitrification of the ammonia in the recycled waste water. These are slow processes but their effects on the soil gradually become evident.

3.1 Heavy Metals Soils irrigated with effluents from Beer Sheba waste water treatment plant (Kaplan et al,1987) containing (in mg/l): Zn 130+/- 45; Cd 1.1+/-0.9; Pb 32+/- 6; Cu 24+/-15, show at the upper 50 cm layer a gradual increase in the concentration of these metals along the years (the soil was irrigated up to 20 years with these effluents) from concentrations below detection level (cadmium) to (in PPB) Zn 120+/-49; Pb 225+/-44, & Cu 144+/-47. Whether this accumulation of metals (of which only 4 were studied) will develop into an environmental problem, and how contaminated soil will be treated, is a question that cannot be answered at present.

3.2 Ochre in Drainage Systems A different issue associated with agriculture in the desert, is that there is frequently a high table of saline ground water below surface, and irrigation is possible only if combined with the instalation of a drainage system which prevents elevation of the saline water table to the root zone. These drain pipes get frequently clogged by iron bacteria under specific conditions: The presence of 50-100 ppb of iron in anaerobic ground water flowing into an aerated drain pipe, will usually induce the development of bacteria of the genus Leptothrix and generate a gelatinous mass (ochre) that will clog the drain pipe within several weeks. This problem is not restricted to the desert environment, but arid coditions aggravate it due to the high salinity of the ground water.

In Neot Kikar, a village Ca.15 Km south of the dead sea, saline ground water is present at 180-200 cm below surface, containing ~100 ug/l Fe++. Drainage systems built to keep the water table below the root zone become useless as they got rapidly clogged by ochre. We have found that changing the design of the drainpipes so that they are kept full with flowing anaerobic water prevents buildup of ochre as well as removing it from clogged pipes (Abeliovich 1985).

4. Industry

Industry located in dry areas generates a different set of environmental problems. The industry puts a great effort into water economy, and uses as little water as possible. The result is often that these industries discharge effluents which are both very saline and very concentrated, and therefore might be resistant to biological treatment, although the contaminants themselves are readily biodegradable under suitable conditions (belkin et al., 1993, 1994). This in turn leads to a wide spread contamination of land by pollutants which are non biodegradable in conventional waste water treatment systems and require special adaptations.

4.1 Ramat hovav industrial park For many years, arid zones were considered in Israel as the preferred choice for polluting industries, as it was thought that the desert is an inert environment which can tolerate any load of contaminants. Thus in one such industrial park, where a wide range of chemical industries are located,reactor effluents were freely discharged for many years, either directly into a dry river bed, or, when the environmental dangers associated with this practice were realized, experiments were carried for several years to evaporate these effluents by sprinkling them over an area of Ca. 30 ha. The result of this experiment is a large scale contamination of the site. In extraction experiments (unpublished results),extraction with water or 0.01N NaOH required many hours before any appreciable amount of organic carbon could be detected in solution, while in presence of detergents prolonged extraction time resulted in the detergents themselves being adsorbed to the soil particles. This soil contains 10-15% organic matter(w/v),while the soil in adjacent uncontaminated sites contains less than 0.1% (w/v) water extractable organic matter.Lack of water has here 2 effects: it reduces distribution of toxic organics, which might be considered an advantage, but on the other hand it prevents natural biodegradative processes from eliminating toxic materials by microbial activity.

From an environmental point of view, these sites are time bombs, because a characteristic feature of the loess soil in the area is that it absorbs water very slowly, and therefore the few rain storms that do occur in the area do not induce enhanced biodegradative activity by bacteria in the soil, but instead cause surface runoff, erosion and washout of the organics together with the upper soil layer, thus distributing the contaminants to wide areas down stream.

Although the soil on site is dry for 9-10 months throughout the year, it is inhabited by a microbial population capable of degrading organics which are abundant in it. When the rate of degradation of specific markers such as Tribromophenol (TBP), in soil extract amended with bacteria from an experimental sequential batch reactor, was compared with its rate of degradation in the soil extract by the natural microbial population present in the soil (we assume that the TBP is totally degraded as no new peak appeared upon the disappearance of the TBP peak), it was found that both populations removed TBP from the extract, though the adapted microbial population from the reactor was much faster than the natural population.

Although the soil on the contaminated site was inhabited by a bacterial population capable of degrading both the chemicals that were used as markers as well as other pollutants,these remain trapped in a stable condition and it seems that no or very little biodegradative activity takes place on site, demonstrating again the vulnerability of the desert environment to chemical pollution, because bacterial activity is arrested by lack of water.

While glucose enhanced degradative activity by the enrichment culture under aerobic conditions, it was found that under anaerobic conditions it inhibited degradation of TBP by both the natural soil microbial population and a reactor enrichment culture. Indicating that different metabolic pathways and possibly different bacteria are involved in the degradation of TBP under aerobic and anaerobic conditions.

As mentioned earlier, TBP was used only as a convenient marker, and although it was totally degraded, this by no means implies that all other contaminants were removed as well. Thus we find that toxicity (in Microtox units) increases in aerobic biodegradation experiments 3-4 fold,demonstrating that end products of incomplete biodegradation are frequently more toxic than the original contaminants.

5. Conclusions

The desert environment lacks the self purification mechanisms that keep the wet environment free of biodegradable contaminants, and It is therefore more sensitive to the long term effects of permanent or uncontrolled release of such pollutants than the wet environment. In the desert, both agricultural pollutants and industrial waste water have to be treated at their source,as contaminants will not disappear naturally, even though they are biodegradable in the laboratory.

References

Abeliovich, A. (1985): Avoiding ochre deposits in soil drainage pipes. Agricultural Water Management, 10: 327-334.

Kaplan, D. Abeliovich, A. and Ben-Yaakov, S. (1987): The fate of heavy metals in wastewater stabilization ponds: I. Changes in metal distribution along the treatment path. Water Research 21: 1189-1194.

Belkin, S., A. Brenner and A. Abeliovich. (1993): Biological treatment of a high salinity chemical industrial wastewater. Wat. Sci. Technol., 27:105-112.

Belkin, S., A. Brenner, A. Lebel and A. Abeliovich. (1994): Treatment of high-strength, complex and toxic chemical wastewater: End-of-pipe "best available technology" vs. and in-plant control program. Wat. Sci. Technol., 29:221-233.

沙漠研究 5S, 215-218(1995)
Journal of Arid Land Studies

Bioremediation: An Overview Based On International Project Experience

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Abstract - Bioremediation is emerging rapidly as a cost effective method for the remediation of contaminated sites, particularly those contaminated with petroleum hydrocarbons. The technology has many advantages over conventional cleanup methods, but it also has certain limitations. This paper discusses the basic science behind the process, assess the process performance and provide an over view of the technology based on the results and project experience obtained from field scale bioremediation studies conducted in the USA, Germany and Kuwait.

Key Words : Bioremediation, Petroleum Hydrocarbons, Biodegradation, Surfactant

1. Introduction

Biological treatment has rapidly become the technology of choice for remediation of soils contaminated by petroleum constituents. In the USA, several superfund sites were completely remediated using biological treatment and the same technology is currently being considered for 140 additional sites. Numerous factors have contributed to the rapid and successful commercialization of bioremediation at a global level, including the low capital and operating costs, minimal specialized equipment requirement and public acceptability. Bioremediation is not however a universal solution for all contaminated sites, Gibson and Sayer (1992). The effectiveness of the technology depends on many factors and treatability studies is, therefore, recommended prior to full-scale implementation (Blackbum et al., 1993). This paper provides an overview of the technology based on international experience gained from field-scale bioremediation projects in North America, Europe and the Middle East, involving oil-contaminated sites.

Oil contaminants represents a highly complex mixture of hydrocarbons, which can be divided into crude oils, petroleum distillates, lubricating oils and fuel oils. The main chemical fractions of oil include: naphthenes (cycloalkanes), normal alkanes, isoalkanes and aromatics, together with a variety of non-hydrocarbon compounds. The latter include sulphur, nitrogen, and oxygen-containing compounds, porphyrins and asphaltenes and resins, these last two groups being of higher molecular weight material. Trace elements may also be completed with these constituents.

2. Biotechnology of Oil Detoxification

There is a vast literature on the subject of oil degradation by microorganisms which cannot be covered in this paper due to the limited space. In general, more than one species of microorganism is needed for complete mineralization of oil contamination. The principal bacterial genera responsible for oil degradation in the soil environments comprise mainly *Pseudomonas, Achromobacter, Arthrobacter, Flavobacterium, Micrococcus, Nocardia and Bacillus* (Bossert and Bartha, 1984; Atlas, 1981; Leahy and Colwell, 1990).

Of the various petroleum fractions, n-alkanes, n- alkyl-aromatic and aromatic compounds of the c_{10} - c_{22} range tend to be the most readily degradable, shorter chain compounds being rather more toxic. Compounds which exceed c_{22} tend to be degraded more slowly due to a reduction in solubility and bioavailability. Branched chain alkanes are degraded more slowly than corresponding normal alkanes. Cycloalkane degradation rates are somewhat variable but tend to be much slower, often including several microbial species. Components which exhibit the greatest resistance to biodegradation comprise the highly condensed aromatic and cycloparaffinic structures, together with tars, bitumen and asphaltic materials which have the highest boiling points (Atlas, 1981). Asphaltenes can also appear as the resistant microbial products of petroleum hydrocarbons in soil. Crude oil, tarry waste and oily sludges contain also a fraction known as polyaromatic hydrocarbons (PAHs), some of these compounds, are known to be potent carcinogen, such as benzo(a)pyrene (Cerniglia, 1992). Microorganisms can successfully degrade such compounds to non-toxic end products. Based on our own

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experience, the degree of PAHs degradation in different soils may vary, even under the same optimum growth conditions for microorganisms. Most significant is the effect of the tight PAH binding to the soil fine particles and clay content, Weissenfels (1992). We have also found that the presence of high organic carbon content can result in significant retardation in PAHs degradation due to more than one possible reason, Balba (1993). For example organic carbon may be utilized by microorganisms in preference to the PAHs, the adsorption of PAHs onto the soil organic carbon can also protect them from microbial attack and thus increase their persistence.

3. Bioremediation Strategies

The most reliable way to achieve successful bioremediation is to ensure that appropriate microorganisms are present in adequate numbers and that the physical, chemical and environmental conditions are optimized for their growth and catabolic activities. Microbial strains for site remediation can be obtained from a variety of sources. The obvious source is from the contaminated site itself, using standard microbiological techniques, where it may be assumed that such species will have adapted to the prevailing site and environmental conditions. One of the key properties limiting the degradation of high molecular-weight compounds is water insolubility. It may be possible therefore to enhance their biodegradation by using suitable surfactants, provided these surfactants are non-toxic and biodegradable (Fry et al., 1993). However, the success of surfactants in enhancing oil degradation has been so far, somewhat variable and further investigations in this area are needed. Several hydrocarbon-degrading microorganisms can produce very active oil emulsifying agents. The manipulation of soil conditions to enhance the proliferation of these type of microorganisms is considered more cost-effective than the application of chemical surfactants. The selection and optimization of bioremediation design parameters are usually established during the treatability studies, using microcosm tests (Balba and Bewley, 1992).

4. Case Studies

The following case studies provide few examples of the application of bioremediation to remediate oil- contaminated sites in the USA, Germany and Kuwait. Our intention is not to discuss in detail these projects, but only to present a global overview of the performance and effectiveness of this technology.

4.1: Bioremediation of Heavy Petroleum Hydrocarbon-contaminated soil, California, USA

Numerous locomotive maintenance yards are operated worldwide by major railroad companies. An increasing number of these yards contains soil contaminated with various concentrations of petroleum hydrocarbons. The source of the contamination is refueling, operation and general locomotive servicing where hydrocarbon -type products such as diesel fuel and heavy motor oil are routinely used. The project was conducted with the support of the Alternative Technology Section of California's Dept. of Health Services under the California Hazardous Waste Reduction Grant Programme. Its objective was to develop and field demonstrate a cost-effective biological treatment programme, specifically for this type of heavy engine oil contamination (Balba and Ying, 1991). The programme consisted of a multi- step laboratory treatability study followed by field demonstration (Balba and Ying, 1991). The soil contained mostly linear and branched alkanes in the c_{22} plus range (Fig. 1) with boiling point above 200 ^{0}C. The laboratory programme included also intensive microbial and nutrient optimization microcosm studies.

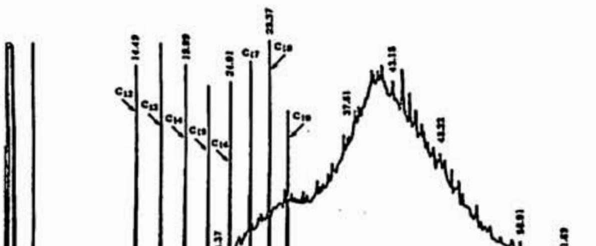

Fig.1 Gas chromatographic analysis of heavy engine oil

The field demonstration involved 120 m^3 of soil contaminated with heavy engine oil (>10%) which was treated by the bioaugmentation of the soil with a mixture of microbial inocula and organic and inorganic fertilizers, which was developed in the laboratory, and routine tilling and irrigation. Key biodegradation parameters were monitored regularly and adjusted when required. The treatment beds were sampled once every month for total petroleum hydrocarbon concentration (TPH) which was analyzed routinely by EPA Method 418.1, and intermittently by GC/FID analyses to confirm biodegradation. Surprisingly and in spite of the complex nature of the contaminant and the extremely elevated starting concentration (100,000 mg/Kg), more than 85% reduction in oil concentration was removed within 28 weeks of bioremediation (Fig. 2). Residual oil constituents consisted mainly of asphaltenes, resins molecules which were slow or hard to degrade.

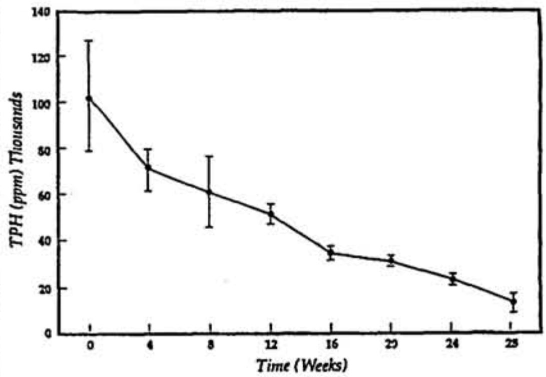

Fig.2 Bioremediation of heavy petroleum oil in soil at a railroad maintenance yard (Figure represent the means of 13 samples)

4.2: Bioremediation of An Oil- Polluted Refinery Site, Germany

This study was conducted to assess the feasibility of bioremediation within an oil-polluted refinery site in Germany (Ellis, et al., 1990). The site occupies several hectares and oil contamination penetrated the soil to the depth of more than 6 meters, and therefore excavation and removal of the polluted area would prove very expensive. Furthermore, certain surface layers of the refinery soil contained contaminated clay lattices not amenable to insitu bioremediation. There-fore,a dual treatment process was designed, incorporating onsite bioremediation of heavy contaminated excavated clay soil (200 m^3), combined with insitu bioremediation for deeper layers (1600 m^3). Both the onsite and insitu bioremediation treatment systems were supplemented with surface active agent, nutrient, microbial inocula and sufficient aeration. The soil was monitored regularly for TPH concentration by Infrared Spectroscopic methods and biodegradation was also confirmed by GC/FID analysis. The result showed that bioremediation of the excavated soil (on-sitetreatment) reduced oil hydrocarbons concentration from 12,800 mg/kg to less than 2,000 mg/kg within 24 weeks (84% reduction). Similarly, the insitu treatment showed significant statistical drop in the oil hydrocarbon concentrations. Their level was reduced from 180 mg/kg to 26 mg/kg (86% reduction) within 15 weeks (Fig. 3).

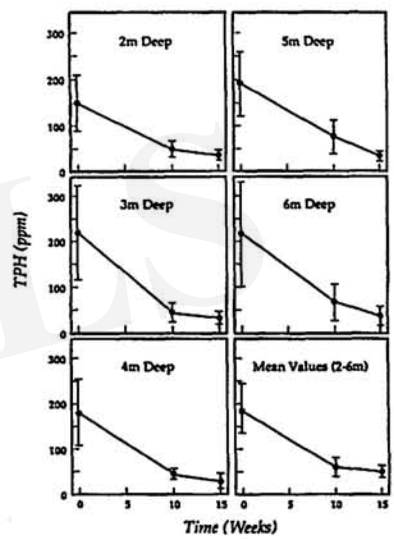

Fig.3 In situ treatment of refinery land. Figure indicate the mean concentrations of oil hydrocarbons at various depths (20 samples per depth)

4.3: Bioremediation of Oil- contaminated Desert Soil in Kuwait

Over six hundreds of Kuwait's oil wells were exploded during the Iraqi invasion and occupation of the country in 1990, resulting in massive terrestrial and marine contamination with crude oil. The volume of contaminated soil is estimated at more than 33 million m^3 which needs to be treated so that it does not pose a critical health hazard to man and also to stimulate the restoration of damaged ecosystem.

During the past several years, Kuwait Institute for Scientific Research (KISR) conducted intensive studies to develop and assess the feasibility of bioremediation as an alternative option for the remediation of the oil contaminated desert soil (Al-Awadhi, et al., 1992). The studies involved the remediation of several hundreds cubic metrers of oil-contaminated desert soil by bioremediation methods: a) land farming, and; b) windrow composting piles

Oil contamination level ranged between 1.3 % to 8.9 % TEM.

In the landfarming treatment, the oil concentration was reduced by 80 % within 6 months in the lightly contaminated plots and 60% within 12 months in the heavily contaminated plots. In the soil composting pile treatment, oil concentration was reduced by 80-88% within 10 months. In all cases, there was a significant reduction in PAHs concentration (60 -90%). Moisture level was identified as the critical process parameter under Kuwait harsh climatic conditions. The inoculation with white rot fungus *P. chrysosporium*, resulted in a noticeable enhancement in oil biodegradation. The growth of plants appear to stimulate oil degradation, plant roots enhance microbial population and activities in contaminated soil, especially in the rhizosphere zone (Anderson et al., 1993). Alfalfa vegetation results in much cleaner soil than the control as was evident from the analysis of total petroleum hydrocarbons (TPH), total extractable matter (TEM) and PAHs (Fig. 4).

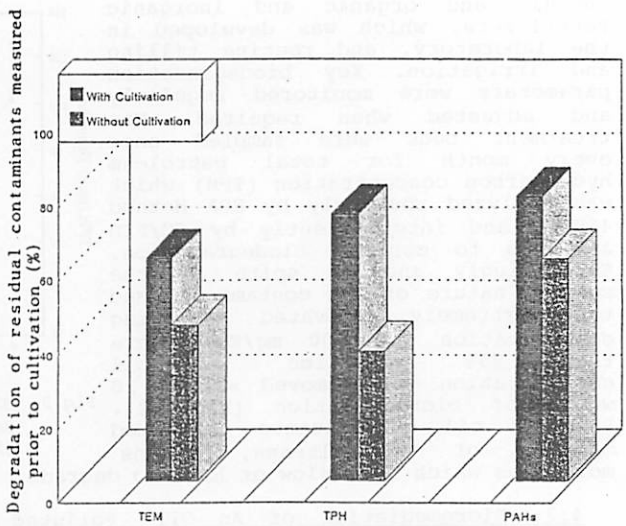

Fig.4 Effect of plant cultivation after 12 months bioremediation on degradation of TEM, TPH and PAHs

5. Conclusion

A substantial literature documents the successful decomposition of petroleum hydrocarbons in soils. Experience gained from projects conducted in various countries, suggests that biological treatment is a very effective technology for remediating oil- contaminated sites. The process resulted in a significant on-site destruction of the pollutants, even under complex site characteristics and harsh climate. However, a successful remediation program can only be properly instigated once the problems of a particular site are fully understood so process design parameters can be fully optimized. Advancements in the relevant areas engineering, biochemistry and molecular biology are likely to improve further the efficiency and cost effectiveness of bioremediation.

References

Al-Awadhi, N., Abdal, M.S., Briskey, E.J., and Kenneth, W. (1992): In Proceedings at the 85th Annual Meeting and Exhibition, Kansas City, Missouri, USA, (June 21-26)

Al-Awadhi, N., K.J. Williamson and J. D. Isok. 1993: In Hydrocarbon Contaminated Soils and Groundwater, ed. P. T. Kostecki and E. J. Calabrese, Vol. 3, pp. 9-21.

Anderson, T. A., Guthrie, E. A., and Walton, B.T.(1993): Environ. Sci. Technol. 27: 2630-2636.

Atlas, R.M. (1981): Microbial Review, 45: 180-209.

Balba, M. T. and Ying, A. C. (1991): Proceeding of the Sixth Annual Conference on "Hydrocarbon Contaminated Soil". University of Massachusetts, Amherst, MA., USA.

Balba, M.T. and Bewley, R.F. (1992): In Organic Contaminants in the Environment (ed. K.C. Jones). Elsevier, London, pp. 236-274.

Balba, M. T. (1993): In Exploitation of Microorganisms (ed. D.G. Jones), Chapman & Hall, London pp. 371-410.

Blackbum, J.W., Harner, E.J., Robins, W.K., Prince, R.C., Clark, R.M., Atlas, R.,. and Wilkinson, J.B. (1993): Biodegradation, 4: 207-230.

Bossert, I. and Bartha, R. (1984). In Petroleum Microbiology, (ed. R.M. Atlas) Macmillan, New York, pp. 435-473.

Cerniglia, C.E. (1992): Biodegradation, 3:351-368.

Fry, I.J. Chakrabarty, A.M. and Defrank, J.J. (1993): Proc. 1992. CRDEC Science Conf. on Chemical Defence. Edgewood, Maryland, USA. p. 362.

Gibson, D.T., and Sayler, G.S. (1992): Scientific Foundation of Bioremediation: Current Status and Future Needs - A Report from The American Academy of Microbiology, 1-23, Washington D.C.

Leahy, J. G. and Colwell, R. R. (1990): Microbiol. Review, 54: 305-315.

Weissenfels, W.D., Klewer, H., Langhoff, J. (1992): Appl. Microbiol Biotechnol, 36: 689-696

沙漠研究 5S, 219-222(1995)
Journal of Arid Land Studies

Evaluating Technology for Automated Determination of Crop Water Status

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Abstract - In this study, we assess two technologies, ultrasonic acoustic emissions and infrared thermometry, for automated determination of crop water status. Measurements of acoustic emissions, micrometeorological variables, and crop water status were conducted in California winegrape vineyards in which water was periodically withheld to decrease vine water status. For acoustic emissions, the total number per day detected in stems was well correlated (r^2= 0.95) with the midday leaf water potential of that stem. The infrared canopy temperature measurements were used in conjunction with other micrometeorological inputs in several models of the canopy energy budget. The more rigorous models were able to represent discontinuous canopy structure and thus provided superior estimates of vineyard water status.

Key Words: evapotranspiration, irrigation, energy budget, acoustic emissions

1. Introduction

Environmental concerns and increased nonagricultural demand for water are putting irrigated agriculture in arid and semi-arid environments under increasing pressure to utilize less water more efficiently. Fundamental to prudent decisions about when and how much water to apply in crop production is knowledge of crop water status. An unequivocal analysis of crop water needs can only be accomplished by a plant-based system since plant water status represents an integration of the evaporative demand created by prevailing daily weather conditions and the supply of soil water that is relatively insensitive to daily weather changes. Of the two plant-based systems presently available, pressure chamber analysis of plant water potential is excessively time consuming and not suited to automation, and the other, hand-held infrared thermometry, lacks resolution and reliability. Both require technical expertise and frequent sampling by hand. As a result, these approaches are seldom utilized in production.

We report here on initial feasibility studies conducted for two technologies for automated assessment of crop water status: application of new field-level, micrometeorological-based energy budgets and individual plant-based detection of acoustic emissions (Sanford and Grace 1985). The energy budget models can be used to determine both evapotranspiration (ET) and stomatal conductance. Test applications for both technologies were conducted in winegrape vineyards, where moderate water deficits are used to increase crop quality (Williams and Matthews 1990).

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2. Materials and Methods

Field experiments were conducted in a commercial *Vitis vinifera* `Cabernet Sauvignon' vineyard near Lodi, CA, USA. Vines were drip irrigated every other day; water deficits were imposed by withholding water from some vines for several days, and water status was determined by the pressure chamber and leaf porometry techniques. Acoustic emissions (ae's) were detected with a piezoelectric detector appressed to basal shoot internodes, and signal processing equipment that allowed selection of a threshold signal level to avoid ambient acoustical noise.

The energy budget approach was conducted in three phases: computer model development; field experiments; and model verification using field data. The modeling approach was to develop energy budgets having two levels of complexity - a simple "Bigleaf" model and a more complex "Multilayer" model. The Bigleaf approach was applied as both single- and two-layer resistance models, similar to Kustas (1990), although there was little difference between the two in performance. The resistance network was solved for the residual canopy resistance and converted to stomatal conductance units by dividing by the leaf area index. The Multilayer model was constructed around the approach outlined by Norman (1979) where submodels are included for light penetration, soil energy, leaf energy, and turbulent transport. The approach was augmented to include vertical and horizontal stratification of light penetration and leaf energy budgets. Sources and sinks of heat and water vapor were averaged across the lateral dimensions for constructing the vertical profiles of air temperature and humidity using gradient diffusion (K-theory) turbulent transfer (Thom 1975).

Field experiments were conducted in 3 commercial vineyards to simultaneously make measurements of environmental conditions and of vine water status during periodic drought cycles. Canopy geometry was measured and architecture was quantified by leaf area density measured as a function of height by horizontal point quadrats. The environmental measurements were made by instruments mounted on a tower located at the downwind end of the vineyard. The measurements made were: wind speed and direction, air temperature, humidity, net radiation, shortwave radiation, soil heat flux, canopy and bare soil temperatures (infrared thermometry). Additionally, above-canopy fluxes of sensible heat and latent energy were measured using eddy correlation.

Each model was verified using, as inputs, the diurnal environmental data that was collected in the field. The outputs of the models (ET and stomatal conductance) were compared to measured values.

3. Results and Discussion

3.1 Acoustic emissions. Moderate water deficits cause substantial losses in stem hydraulic conductivity of potted vines (Schultz and Matthews 1988). These losses are attributed to cavitation events in stem xylem as tension increases during water deficits. Cavitations are detectable as ultrasonic emissions (Sanford and Grace 1985). Preliminary experiments in the growth chamber demonstrated a well behaved pattern of ae's, increasing with water deficits and decreasing upon recovery. Therefore, further experiments were conducted in a commercial vineyard to test the feasibility of using acoustic emissions technology for automated estimation of vineyard water status. Experiments were repeated at two stages of development, before and after the onset of fruit ripening. Sensors were attached to the basal internodes of two sun shoots on vines that were continuously irrigated and on vines from which water was withheld over eight days. Daily totals of ae's were recorded and regressed onto the midday leaf water potential for the same shoots (Fig. 1). The data show that accumulated ae's increased rapidly after midday leaf water potential decreased below about -1.0 MPa. A 2nd order polynomial regression of daily total ae's to midday shoot water potential produced $r^2 = 0.95$. Thus the application of acoustic emission technology to estimate vineyard water status is feasible and warrants further investigation.

3.2 Canopy energy budgets. Our results indicate that, using only a small number of on-site environmental measurements, vineyard water status may be estimated for a representative portion of a vineyard to reasonable accuracy. The quality of the estimate is greatly dependent on the canopy model to which these variables are input. Both the Bigleaf and Multilayer canopy models were capable of estimating vine stomatal conductance under differing levels of water stress. The Multilayer model, however, produced estimates of stomatal conductance that were considerably more representative of the values that were measured manually (Fig. 2). This is indicated by superior correlation coefficient and a slope more near unity (Fig. 2).

Using the same set of environmental inputs, each model estimates instantaneous latent energy flux from which daily ET can be obtained. The Bigleaf model produced relatively poor estimates of ET (r^2=0.46, slope=0.45), but the Multilayer model was able to provide excellent estimates (r^2=0.80, slope=0.99).

The Bigleaf-type models may be made suitable for continuous, low-growing canopies. However, it failed to perform adequately in a vineyard canopy with hedgerow configuration and large expanses of bare soil. The failure of the Bigleaf model can be attributed to its simplifying assumption that all energy transfer and evaporation occur on a single hypothetical surface whereas these processes occur on a multitude of surfaces including leaves and soil in vineyards. The soil contributes sensible heat flux that is advected into the canopy, increasing evaporative demand.

The Multilayer model is capable of representing the light environment within the foliage, the energy transfer by the soil and various leaf surfaces, and the transport of heat and water vapor into the air so that the canopy environment can be represented in detail mathematically. This added rigor lends itself to superior estimates of vineyard stomatal conductance and ET with only a small number of inputs from field sensors. Further improvements may be realized by expanding the current one-dimensional turbulent approach into two dimensions to accommodate the lateral variation in sources and sinks of heat and water vapor. This will involve expanding the turbulent transport submodel from a relatively simple K-theory treatment to a two-dimensional second order closure approach (Meyers and Paw U 1987, Wilson 1989).

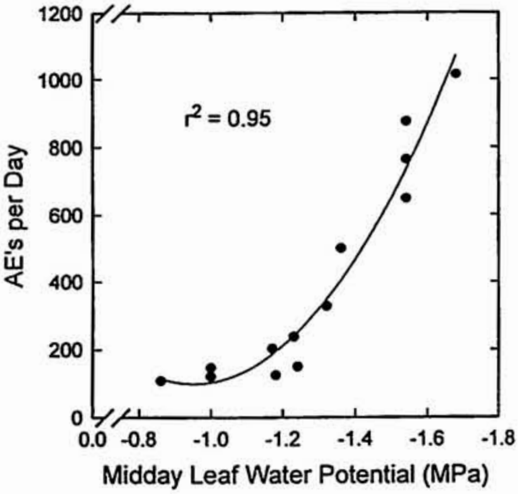

Figure 1. Daily ae's from field-grown shoots at various water potentials.

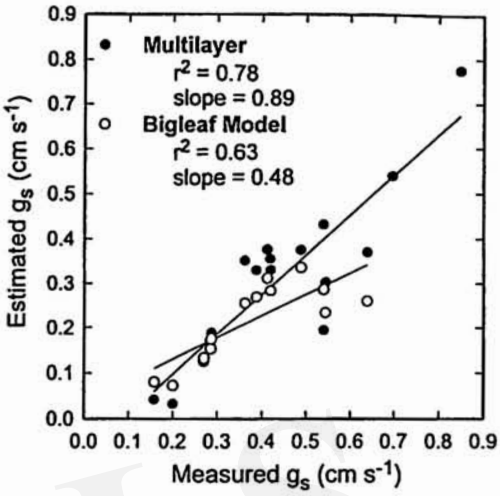

Figure 2. Energy budget model estimates of stomatal conductance versus the mean of measured stomatal conductance for sunlit leaves.

References
Kustas, W. P. (1990): Journal of Applied Meteorology 29:704-710
Meyers, T.P. and Paw U, K.T. (1987): Agricultural and Forest Meteorology 4:143-163
Norman, J. M. (1979): Modification of the Aerial Environment of Plants. ASAE monograph no. 2.
Sanford A.P and Grace, J. (1985): Journal of Experimental Botany 36:298-311
Schultz, H.R. and Matthews, M.A. (1988): Plant Physiology 88:718-724.
Thom, A.S. (1975): Vegetation and the Atmosphere. Vol. 1. Principles, J.L. Monteith, editor.
Williams, L.E. and Matthews, M.A. (1990): Irrigation of Agricultural Crops. BA Stewart and DR Nielsen, editors. American Society of Agronomy Monograph.
Wilson, J.D. 1989. Estimation of Areal Evapotranspiration. IAHS publication no. 177.

沙漠研究 5S, 223-228(1995)
Journal of Arid Land Studies

New Soil Improver for Plant Growth

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Abstract-[GEO-SANGREEN], chemically converted material from Coal Fly Ash for plant growth has been developped. The significance of [GEO-SANGREEN] is proved to bring greening effect on acid soil which has yet been attained by the existing technology as well as on normal soil.

key words: Greening, Coal Fly Ash, Acid Soil

1. Introduction

To prevent devastation and to promote greening of wasted land are some of the most important tasks of the 21st century. Effective use of wastes and development of technique for recycling are equally important for preventing environmental pollution. We have developped an effective material for these objectives. The Nippon Steel Corporation and The Sangyo Shinko Company, in cooperation with The Clean Japan Center, have developped [GEO-SANGREEN], soil improver which is chemically converted from coal fly ash.

The soil application procedures have been investigated by The Kitagawa Ryokka Kougyo Company. Scattering [GEO-SANGREEN] to normal soil materialized significant plant growth. It also brought greening effect to acid soil which existing technology has yet enjoyed success.

As [GEO-SANGREEN] is also effective as water/air treatment agent, the use of this material has been spreading rapidly in areas where environmental improvements are needed.

2. Strategy for Development

In view of Agronomical Science, coal fly ash, product of botanical circulation, contains inorganic nourishment generated by photosynthesis. For this character, we came to the conclusion that coal fly ash should be used effectively in creating fertile agronomical environment.

Two important elements for promoting greening are meteorological factors such as daylight, precipitation, temperature, etc. and soil condition. One of the obstructions for greening is strong acidity in soil. This kind of soil has been neutralized by adding calcium-containing materials. However, this system is not effective in view of being harmful to plant by supplying too much calcium, lacking abilities of reserving water and fertilizer, and durability of effects. Therefore, new soil has to be introduced instead of calcium-containing material. This process is costly.

To improve acid soil, we have gone through many experiments on chemical treatment aiming at effective use of coal fly ash. In consequence, we successfully developped [GEO-SANGREEN] as soil improver.

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3. Production Process and the Characteristics of [GEO-SANGREEN]

Production plant was constructed in April, 1990 and its product capacity is 10,000 ton/year. Proof tests of the process technology were run for 2 years. Market developments and business were started in April, 1992. Fig. 1. summarizes the production process, and Table 1. presents main characteristics of [GEO-SANGREEN].

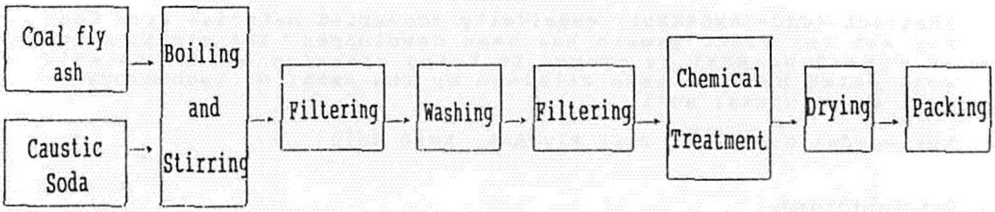

Fig. 1. Process flow

4. Improvement of Plant Growth by [GEO-SANGREEN]

[GEO-SANGREEN] has shown remarkable effects on plant growth applied to normal soil at agro-industrial areas, golf courses and others. Furthermore, it has also proved effective to acid soil (pH≒3) which has been considered difficult for plant growth. Encouraged by these results, the demand for this material is rapidly growing. The results of experiments are presented in Photo 1. and Photo 2. A 2kg/m^2 of [GEO-SANGREEN] was scattered with turf seeds to acid soil of the side-slope where a road was constructed cutting open the mountain.

[GEO-SANGREEN] succeeded in plant growth through neutralization of acid soil without adding soil of good quality.

CHEMICAL COMPOSITION	SiO_2, Al_2O_3, CaO, K_2O, Fe, C, H_2O
SPECIFIC GRAVITY	2.5g/cm^3
MEAN SIZE	10μm
WATER ABSORPTION	104%
CATION EXCHANGE CAPACITY	200meq/100g

Table 1. Main characteristics of [GEO-SANGREEN]

Photo 1. original sight

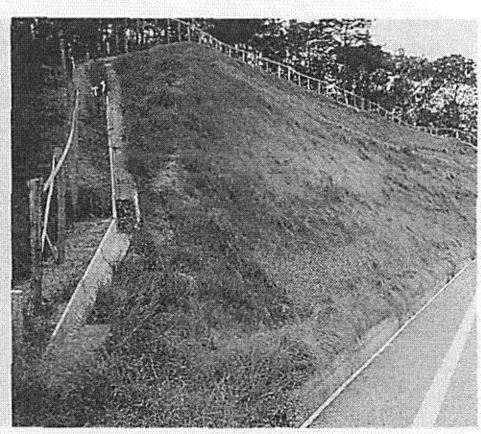

Photo 2. [GEO-SANGREEN] used

5. Mechanism of [GEO-SANGREEN] as Soil Improver

The abilities characteristic to soil improver are 1)reservation of water, 2)reservation of fertilizer, and 3)neutralization of material harmful for plant growth.

5-1 Improvement of water reservation

[GEO-SANGREEN] is capable of containing water up to the same weight as itself. Applied on surface of soil, this water-reserving ability helps soil to preserve water. An example is shown in Fig. 2.

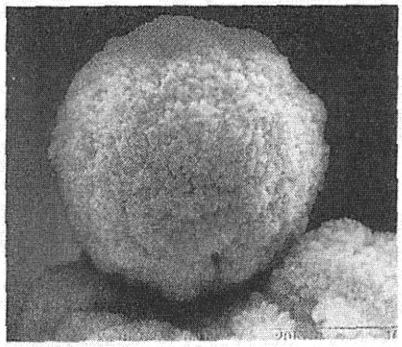

Photo 3. Crystal of [GEO-SANGREEN] (Electron Microscope ×10,000)

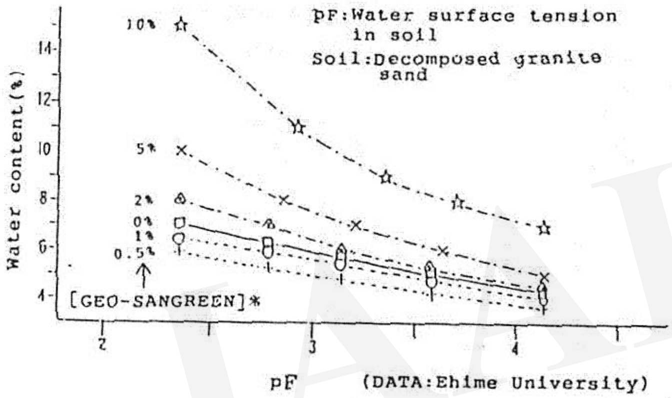

Fig. 2. Relation between [GEO-SANGREEN](%), pF and water content

5-2 Improvement of fertilizer-reserving ability

Cation exchange capacity of [GEO-SANGREEN] is up to 200 meq/100g. In other words, it prevents fertilizer in soil from washed away by rain, and supplies it effectively to plant.

5-3 Neutralization mechanism of acid soil

One of the main causes of generating strongly acidic soil, in case of digging or piling sulfur contained soil, is 1)oxidation by air, 2)sulfuric acid generated by proliferating ferro-sulfur-bacilli.

Up to present, calcium hydroxide and carbonate calcium along with other calcium contained materials are added to neutralize acid soil. However, there is a problem. In neutralizing acid soil below pH=4, too much calcium become obstacle to plant growth.

Neutralization by [GEO-SANGREEN] consists of two factors such as chemical reaction and reaction by exchange between Alkaline ion and [H⁺]ion in soil which is more effective. These reactions allow plants to grow on strongly acidic soil below pH≒4.

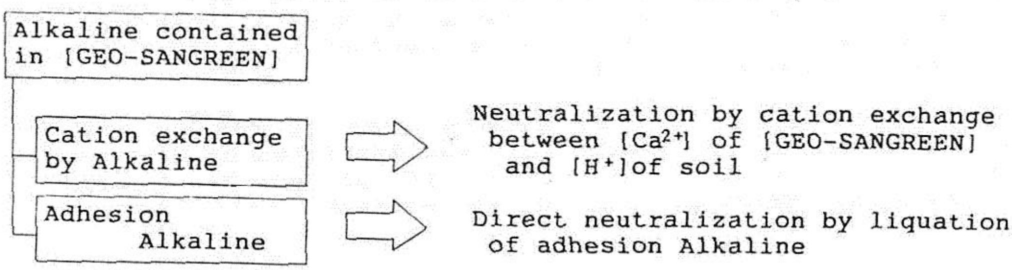

Fig. 3. and Fig. 4. present models of neutralizing process.

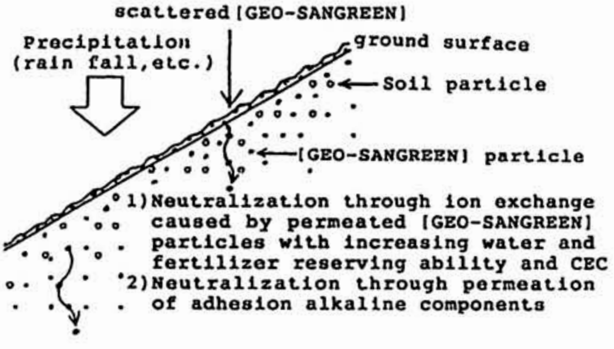

Fig. 3. Schematic model of neutralization

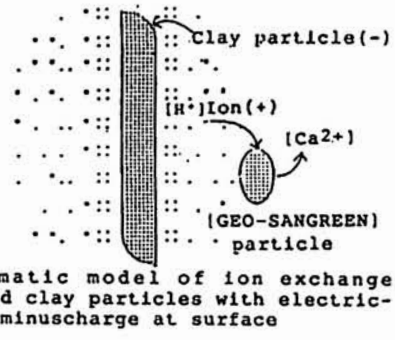

Fig. 4. Schematic model of ion exchange

[GEO-SANGREEN] was scattered on acid soil of the side-slope of road to observe the process of neutralization. Fig.5 presents the process of neutralization when [GEO-SANGREEN] particles in slurry of 10μm of diameter and 2.5g/cm^3 of specific gravity was scattered on soil(pH=3) by 2kg/ m^2.

pH increases as time elapse. After 2.5 months, pH was improved to 5.5 at surface depth of 0~50mm, 4.5 at 50~100mm. These data show that acid soil was improved enough by [GEO-SANGREEN] for plant to grow.

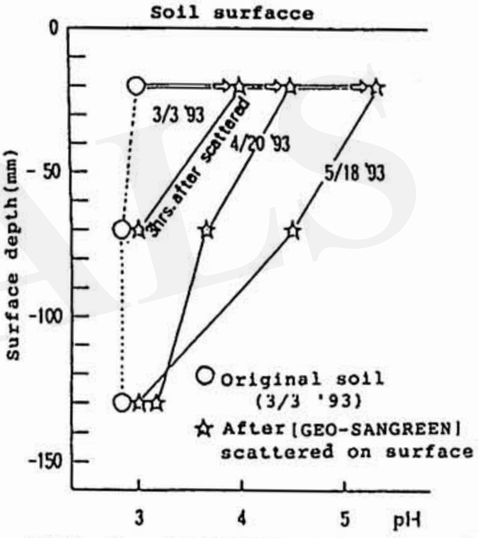

Fig. 5. Transition of pH of soil after [GEO-SANGREEN] scattered

6.Conclusion

6-1 Through 2 years of proof experiments since '90, [GEO-SANGREEN] was developped by chemically converting coal fly ash for improvement of plant growth, especially at acid soil.

6-2 [GEO-SANGREEN] has high cation exchange capacity which improves pH of soil as neutralizer with chemical reaction and strong ion exchange effect. It also developpes water-reserving and fertilizer-reserving abilities.

6-3 Applied to soil of side-slopes of roads, ground development areas where acid soil was generated by digging or piling soil, or to devastated land difficult for plant growth, [GEO-SANGREEN] improves these soil at remarkable efficiency.

沙漠研究 *5S, 227-230(1995)
Journal of Arid Land Studies

Ecotechniques of Water-saving Rice Cultivation o n Sandy land

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Abstract---Ecotechniques are the integrated farming systems which combine rice production and desert improvement. Some good properties of the coarse sandy can be utilized, the seedling of sandy cultivatioin have good quality, and high rice production (9,000 kg/ha) in sandy paddy. The key to water-saving is to put a layer of plastic film in the sandy paddy to prevent water and nutrient seepage. The water consumption on sandy paddy is 1195.2 mm using water-saving irrigation one year. Sand dunes have been converted into sandy paddy. The ecosystem changes include soil organic matter and nutrient increase, and erosion control. Rice production has a high investment in the first year,after one year,the radio of output/ input ratio of 3.1.This technique has been applied by farmers in Horqin Sandy Land, China.

Key Words: Ecotechnique, Rice production, Ecosystem, Sandy land

1.Introduction

Sandy Desertification is major environmental and agricultural problem in the interlacing agropastoral region of semi-arid zone in China. With population growth, the crisis between the arable land decrease, land degradation, human are facing food shortage. Their become serious, in1950,when the population of Zhelimu league of Inner Mongolia grew from 0.86 to 2.90 million and the arable land per capita to decreased from 0.83 to 0.23 hectare. Sandy land conversion arable land has beeen developed by government of China with the aid of scientists. Cultivation of vegetables, fruits, wheat, and soybean and other dryland crops on sandy soils have been conducted on sandy soils (A. Richmond 1984, D.Cheng etc.1986, Matsushima 1978), but sandy paddy rice production has not been reporte.

We made an analysis of two major processes of material differentiation in the sandy desertification processes--the coarseness of soil particles caused by wind erosion and the accumulation of water in the interdune depressions caused by destruction of vegetation. We propose several ecotechniques for water-saving rice cultivation on sandy soils. These include how to establish sandy paddy system, water-saving technique, ecosystem, and input and output analysis. This project began in1992. Now there are 100 hectares of sandy paddy in Horqin Sandy Land, China.

2.The Principle of the Ecotechnique

The ecotechniques are an integrated agricultural system, include control wind erosion, rice production, and nutrient cycling. Rice production include placing a layer of plastic film in the bottom of sandy soil paddy, selection of suitable rice varieties, and implementing water-saving, fertilizer-saving and erosion controlling, no-tillage.The bottomed film, although only 0.03-0.05mm in thickness, can effectively prevent water and fertilizer from seepage. Accumulation of salts from the sandy soil is prevented. Coarse sandy soil has several advantages including loose and porous soil substrate, abundant aerophile micro-organisms, low water and nutrient holding capacity, rapid temperature increase in early spring during the daytime, and quick temperature decrease at night, addittional advantages include irrigation and fertilization control, effective weed control, and effective water and nutrient control for maximum rice production.

3.Methodology

3.1.The farming systems of sandy soil paddy

The farming systems of sandy rice paddy include erosion control, sand hedgerows for shelter from wind, livestock manure supplement, forage production, irrigation and drainage control(Figure 1).

3.2.Cultivation of rice seedlings

The seedling bed was selected in sunny and dry land near the home.The proposed bed was leveled and a ridge the height of 5-6cm, was constructed around the edge.Plastic film was placed the bed and 2cm of sand placed in bed. A greenhouse is erected using plastic film over the bed. Rice seeds were soaked and sprouted. They were sown in the bed, and covered with 0.5 cm of sand. The bed was kept wet and temperature between 15-30 °C. Keep the pH in 4.5-5.5 and add appropriate nitrogen, phosphorus, and and potassium. After 40 days, the seedlings were transplanted to field paddy.

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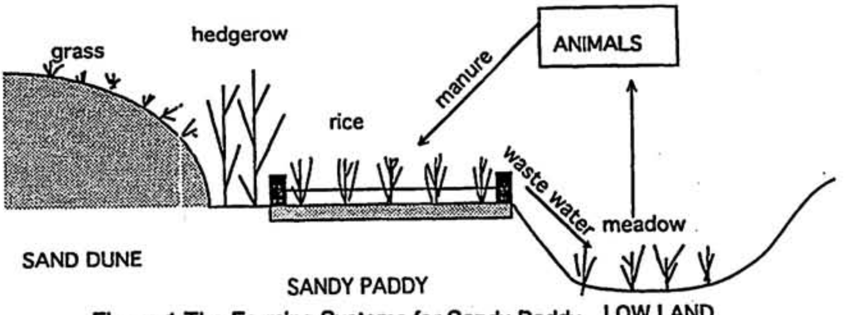

Figure 1.The Farming Systems for Sandy Paddy

3.3. Design of water-saving sandy paddy and irrigation

Sandy paddy was established in semi-flowing and mobile dunes. The dune is made level with a tractor. The water source and irrigation were constructed. The plastic film is placed in the irrigation ditch leading to sandy paddy. Sand of 20-40 cm was placed in the paddy. By irrigation the paddy was kept wet or shallow according to rice requirements.

3.4. Application of fertilizer

Nutrient fertilizer was applied many times at small amounts each time.Total amount of fertilizer (chemical fertilizers and manure) is decided by the rice needs and yield.

4.Results and Discussion

4.1. Seedling cultivation

The quality of seedling is critical for rice production. Seedlings using sand cultivation have high chlophyoll content and are vigorous. The biomass of seedling is 18.6% hgher than traditional cultivation. The roots have more than 2.9 branches per plant, and 2.0cm long.The nice plants develop 0.09 branches per day.The plants are short and strong. After be transplated, the seedling grow quickly, their vigorous growth is advantageous for rice seedlings.

Rice growth is rapid because of the coarse,loose sandy soil and high temperature in bed.The plants have nutrients and large root systems.

Table 1.Comparison of seedling characteristics grown in sand cultivation and tradition cultivation*

Items	sand cultivation	tradition cultivation
content of chlorophyll (mg/g)	2.35	2.12
dry weight (g per plant)	1.95	1.70
dry weight (root, g per plant)	0.54	0.40
plant height (cm)	14.5	11.0
leaf ages	3.7	3.6
energy of root	15.8	7.7
ability of root growth	0.34	0.43
root branches per plant	13.8	10.9
root length (cm)	5.8	3. 8

*Agricultural college of Yanbian, Plant Physiology Lab.

4.2 Water Budget in sandy paddy

Table 2. Diurnal variblity of water in sandy paddy (g/m2)

time stages	transpiration(day)	time stage	condensation (night)
06-07	14.8	00-01	43.3
07-08	145.8	01-02	36.3
08-09	217.7	02-03	40.4
09-10	179.4	03-04	41.6
10-11	355.6	04-05	52.0
11-12	311.9	05-06	29.4
12-23	158.7	18-19	41.2
13-14	235.0	19-20	51.3
14-15	327.2	20-21	47.0
15-16	163.3	21-22	37.0
16-17	292.4	22-23	43.5
17-18	292.4	23-24	41.0
total	2549.0	total	504.1