DESERTIFICATION OR DESERT RECLAMATION? CHANGE IN CLIMATE OR IN HUMAN BEHAVIOUR?

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ABSTRACT: The recent dry spells in North Africa during the period 1968-1986 were characterised by their sudden appearance for which no reliable forecast system exists up to now. Contrary to the prevailing opinions a few years ago it is now believed that the desertification observed in the boundary regions of the desert is for a major part due to climatological changes rather than to human activities.

It is observed that the today's generation handled the dry spells less well than their ancestors did. The reasons for this are discussed. The catastrophe could have been less harsh if proper insight and technological know-how had been used to mitigate the drought. Its most appropriate aspects are discussed both in general terms and on the specific plant level. During the dry spells the best care and the most efficient use of water for crop production are needed to maximize the chances for the survival of plants, animals and man.

1. Introduction

Water is the key factor for initiating or sustaining life in desertic areas. In such regions any fluctuation in water availability has an immediate impact on life.

Due to prolonged geo-climatical conditions some deserts have existed more or less continuously for millions of years, e.g. the Peruvian desert along the West coast of Latin America. Others are only a few thousand years old or even of almost historical age like the ones in North Africa where after the great pluvials of five to six millennia ago, the savanna turned into the Sahara desert. The engravings in the caves of Tassili dating back to the Neolithic are the mute witnesses of this change.

Today the desert encroachment which is going on in many parts of the world but especially in Africa it is of much concern, not only to the scientists but also to the people. The last decades it has been extending at an even greater speed than ever before. Is it necessary to recall that at the beginning of this century the capital of Sudan, Khartoum, was still

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surrounded by savanna vegetation? Today one needs to travel more than 100 miles before the first meagre groups of trees can be found. In North Africa the desertification progresses in many places at an average of 5 km per year. Since the first botanical mapping in those areas was carried out around the turn of this century, it can be verified that the desert extended by more than 1,000,000 km^2 or almost 35 times the area of Belgium. This example is not unique. In all the boundaries of the great deserts, encroachment is a common phenomenon both in the Asian as well as in the American deserts. The average yearly progress of the aridity in some places can be measured by km-sticks.

The boundaries of the deserts are involved most because the population pressure there is strongest. The poorer the people, the more they are pushed to the least fertile lands, but the harder it is to survive. Many children often mean an insurance for survival as they can work the land and take care of the older people. In order to survive in arid conditions they often have to take more from nature than nature can restore.

World opinion was shaken and alerted when the balance of the dry years in the seventies and eighties was made up. In Africa six million people have died from starvation, fifty million are threatened by it, and a hundred and fifty million suffer from malnutricion. The children will bear the consequences, which are both physical and intellectual, for life, even if the food supply would change drastically tomorrow. In Niger and Mauritania the herds are halved, while in Mali the decrease is 30 %. The list can go on, but what does it matter if no adequate remedy can be found. Food supply is one thing, basic understanding of the phenomena followed by education and proper management of natural resources is better. Will mankind be able to bring about more lasting solutions, or is there a real change in climatological conditions?

2. Desertification Defined

Are climatological changes to blame for the widespread desertification? To answer this question, a clear definition must be given first of what is meant by desertification. Let us look at the edaphological meaning of the word. As the metabolism of the plant in those parts of the globe is mainly determined by temperature and available moisture, both parameters also define the growing season. When the growing season over a number of years is reduced from about 150 days to less than that so that crops, even meagre ones, cannot be produced desertification takes place. Deserts are those hot areas where most of the years plant growth is impossible through lack of available water. In such a case one observes that the growing season is too short. Hence it is said that in a desert the growing season is almost next to zero. The fringe of the deserts is characterised by a growing season of 150 days maximum and 0 days minimum (see Figure 1). This FAO map was published in the middle of the last dry period (1968-1986). The 150 days line to limit the border of the Sahel has on average moved already more than 100 km south. On this map the so-called half deserts of East Africa, the Namibian and Kalahari deserts are shown. They are characterised by an average of about 150 growing days but with frequent crop losses due to sudden lack of water. The desertification has progressed there too although less dramatic dry spells have occurred

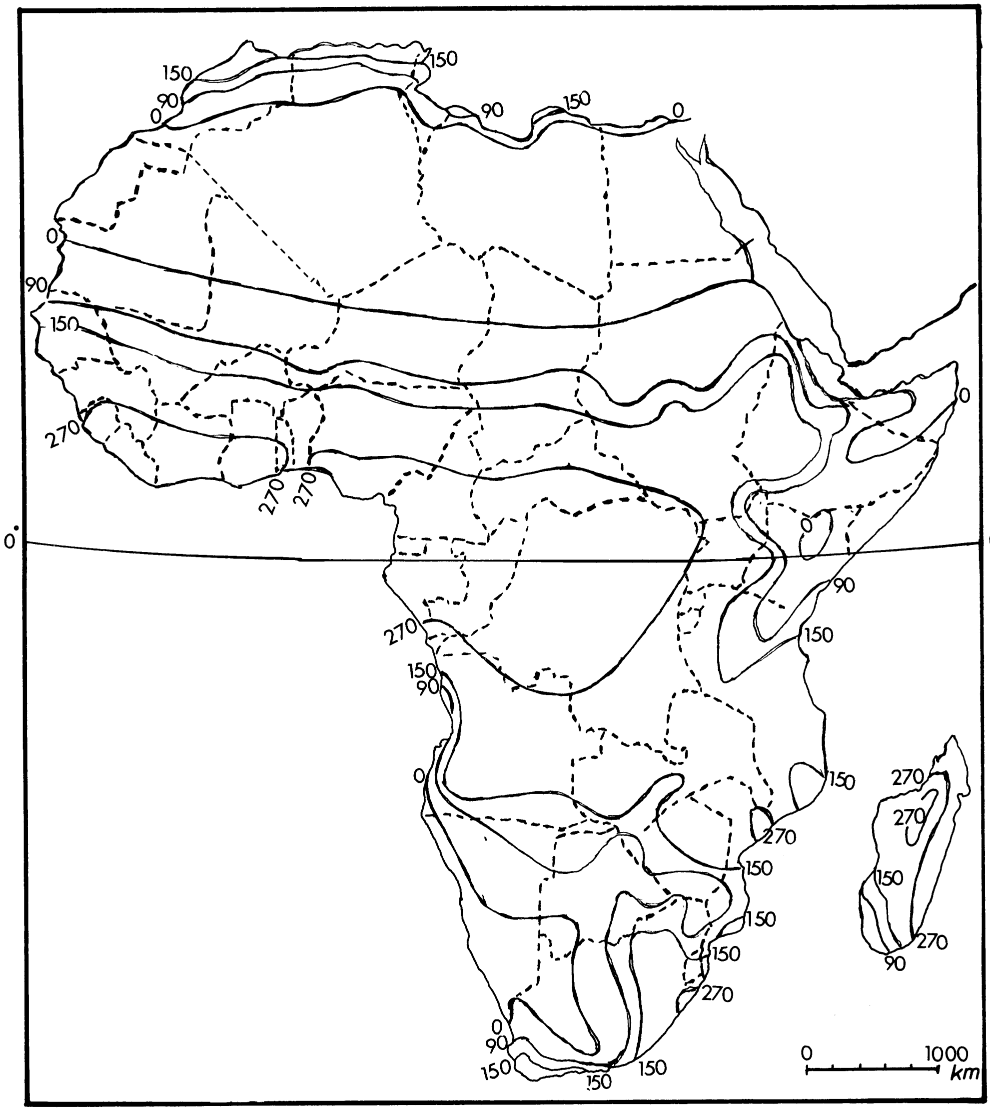


Figure 1. Map of Africa published by FAO (1977), indicating the length of the growth period for the different zones. If it is less then 150 days the area is considered to be desertic. In the Sahel in 1986 the limit of the 150 days growth period has moved on average ± 100 km more South.

there during the last decades while the survival of the population has been satisfactory. It shows the interdependence of human behaviour and climatological conditions with respect to the preservation of nature and good environmental conditions.

3. Climate or Man?

According to the available data it is not yet possible to tell if there has been a real and dramatic change in the climatological conditions to explain the desertification over the past three decades or if there is more to it. The idea is often heard that a change in ecological factors due to human behaviour i.e. cutting trees, overgrazing by herds, not replacing the trees and the grasses etc... are the major causes of the quasi permanent progress of desertification. Can the recently observed changes around the globe such as the so called greenhouse effects induced by man (the increase of CO_2 in the atmosphere which is supposed to cause the destruction of the ozone layer) trigger a definite trend changing the spatial distribution of air-temperature and rainfall? The last point is important as in many well defined parts of the globe rainfall is now higher than the recorded average while in other parts the water deficit has never been so large.

The climatological records of the Sahelian countries show that dry spells are returning much more often in recent times than ever before. According to Rognon (1989) catastrophic dry spells in the last centuries have occurred between 1681-1687, 1738-1756, 1828-1839, 1910-1915, 1939-1944 and 1968-1986. However, a real periodicity cannot be detected. That is why neither the duration nor the short intervals of the climatological change which is now going on could be predicted. This last aspect is more exceptional than the dry spells themselves. It is found recently that in the semi deserts of Southern Africa the rainfall periodicity was correlated with the surface temperature of the oceans with a lag time of 2 or 3 months. Can this explanation help to inprove the prediction of the growing season for these areas? The shorter the periods concerned, the more geographical factors seem to be of importance. They might overshadow the astronomical ones. Hence it becomes more and more difficult to find the real causes of the recent climatological changes even for relatively large areas like the Sahara desert. As long as the primary causes are not fully detected, any forecast will be fortuitous. In general the astronomical factors (see Berger in his contribution to this book) and, for the recent changes, also the solar spot activity cycles must be taken into account. They are characterised by quasi regular periods oscillating between 9.9 and 11.2 years, which in their turn are associated with a cycle of 22 years, correlated with the reversion in the magnetic fields of the sun spots. According to some other scientists the periodicity of 30 years, overshadowed by accidental but local events, should be closer to the real phenomena which the world witnesses for the last three centuries.

As described by Berger et al (1984) Milankovitch proved the link between the variation in the solar insolation and the changes of the terrestrial orbit. A solid theory is still to be developed to explain climatological changes over smaller periods, say over a few decennia which we witness today and which are so important to human life.

4. Human Behaviour During the Recent Dry Spells

The most striking fact of the ongoing desert encroachment in the last twenty years is the great number of victims. Never before dry spells have been so harsh to the human race.

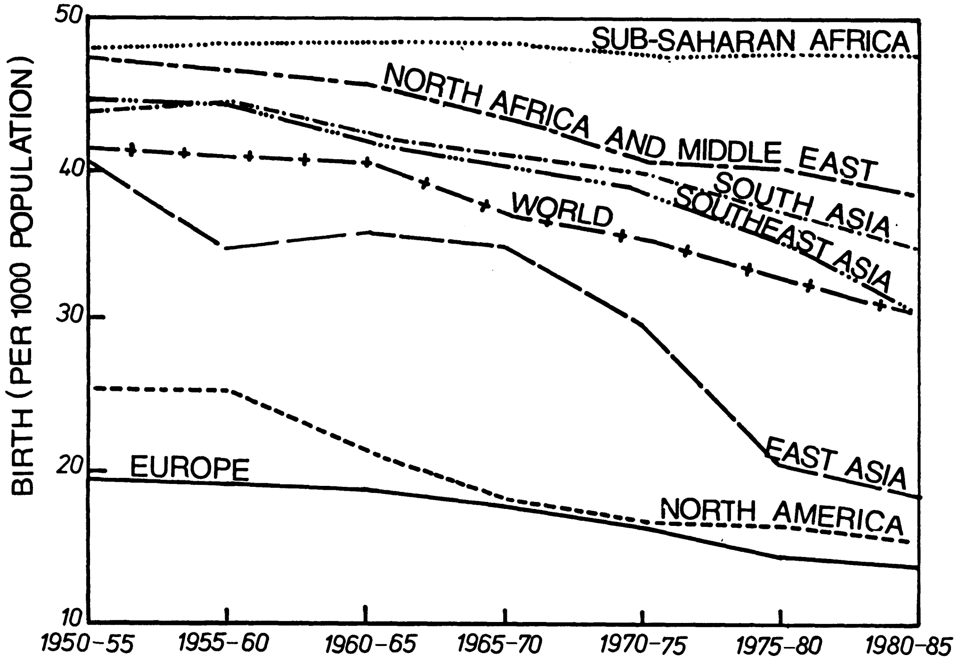


Figure 2. Since 1950 birth rates in the world have declined with the exception to this trend in sub-Saharan Africa, even during the dry spells 1968-1986 (after J.C. Caldwell & P. Caldwell, 1990).

The question arises if the local people are now less well-armed to survive than their ancestors. First there is the much larger number of people to be supported by a shrinking amount of water and ditto available surface of cultivated land. In the boundary areas of the desert the population is now between 6-12 times larger than at the beginning of the century. Sudan, with a population of about 2 million in 1900 jumped to almost 27 million today. As can be seen from Figure 2, birth rates since 1950 in Egypt and in sub-Saharan Africa are above 40/1000 inhabitants. This means that in a life span of about 35 years the population can increase 4 times.

As was pointed out by J.C. Caldwell and P. Caldwell (1990) there exists in these regions a socio-religious system that is not more traditional, primitive or backward than those prevailing in Europe, Asia and the Americas, but it accounts for the persistent high birth rate. In the sub-Sahara society the emphasis lies on ancestry and descendance. It reflects the strength of the ties based on family and lineage. In such a system there is an overpowering need for descendants to ensure the survival of that lineage. Those who live now are the caretakers. They will be blessed or cursed through the intervention of the ancestors, dead or alive, according to their contribution to the survival of that lineage which is after all the respect due to the ancestors from whom they descend.

In such a fast growing society agriculture and livestock production could hardly follow. Through the development effort of the richer nations new methods were introduced and old ones abandoned. The custom of building up reserves for unexpected catastrophes was either not possible because of lack of goods or was not done as money was spent on expendable goods to follow the European way of live. Good husbandry and cunning of the land were just in a transition period when the dry spells came. The nomadic way of life changed to a sedentary one perhaps too rapidly for too many people. They had just started to cultivate the land using fertilisers as shifting cultivation was no longer possible. Human labour was being replaced by animal traction to cultivate the land. Adequate chemical fertilisation was still unknown in many cases and the land was exhausted. Fertilisers, pesticides etc. were not yet common goods. The old system which could bear prolonged dry spells was overthrown and modern technology was not yet fully adapted. This in-between stage, together with the population explosion might be the main reason why the drought was so harsh on the generation of today and why they could not resist the adverse situation as well as their ancestors. On top of that, civil wars were going on in some of the most affected countries. It meant an unprecedented disaster and a blame for mankind as a whole.

5. Desert Reclamation

Is there a way out? A return to the old system is not possible. Only improved knowledge, education and a better understanding of new methods are meaningful. How to save water, how to detect rechargeable water at the fringe of the desert at reasonable depths, how to bring surface water from places of abundance to the dry areas by proper canalization and tunnelling are sensible approaches to improve the situation.

The logical consequence to deal with is to increase the efficiency of the water use. New irrigation systems with minimal losses like drip and low sprinkling irrigation, new drought resistent varieties, the prevention of salinisation, new treatments and feeding systems of the herds etc. all are aspects which have to be properly implemented. Above all, regarding the problem of the population explosion, social and economical issues have to be tackled as well. These items should be studied. This is the major problem.

6. Mitigation of Drought

From the above-mentioned, it is obvious that mitigation of drought covers a vast complex of actions to be carried out in many fields. For the discussion, the essential points should be highlighted. They are: the amelioration and the proper management of the water provision on the macro-, the medium as well as on the micro-scale.

Macro-scale improvements mean gigantic undertakings such as building trans-Sahelian canals, huge dams etc. They are very expensive, and often require international assistance. Among those undertakings, long distance transfer of water is the most important. Successful examples exist in California, Egypt, Israel, and Turkmenistan. A number of huge works are stopped underway or still in the planning stage as their realisation is more than once postponed not only because of the tremendous amounts of money involved but because of the unknown impact on the environment.

In the very recent history, such gigantic works nevertheless are proven to be very adequate. If the Assuan Dam in Egypt had not been constructed about 20 years ago, transporting water from its reservoir over more than 1000 km to the Delta in the north, be it in the bed of the natural river Nile, would have been unreliable and the dry spells in Africa would have had even more dramatic consequences. An additional 40 million people would have been in the starvation zone, which is double the number of those threatened during the last dry spell.

The technology of water transfer has made enormous progress in recent times. It has become a technology on its own. This subject has been discussed in a separate contribution during this symposium.

Much cheaper is the drilling for water at intermediate depth i.e. between $\pm$ 60 and $\pm$ 120 m. Very often it is renewable water. It is much more abundant in the fringe areas of the deserts than ever thought before. On both sides of major rivers like the Nile, the Senegal and Niger etc. often the water carrying layers extend over many tens or hundreds of kilometres. So called "dry valleys" at medium depth are carrying seizable amounts of water. This can be caught in a relatively easy way. Water provided on a medium scale often carries a few grams of salt per litre which is not considered to be optimal, but modern technology knows how to handle such problems.

In the period immediately after the last world war, it still took months to dig a well of 50-60 m deep, mostly of the cone-shape type. With the modern equipment it is only a matter of a few days. On top of that, water from the wells is proven to be the cheapest way to provide the needed moisture to the soil to grow more and better crops. To lift the water, it costs less than a few dollar cents per m^3 per 10 meter. It is most recommended as around each well easily 50 to a few hundreds hectares of agricultural lands can be developed. In general, the owners of the well are also the users of the water. They manage it carefully and feel a responsibility. It makes a complete difference with the huge water supply organisations where the care for the water is often an anonymous issue. At depths beyond 3-400 meter fossil water can be detected. Special studies in North Africa have proved that the reserves are often impressive. In general, the salt content of the water can be relatively high. For the time being these resources are practically not exploited. The level of knowledge on how to use water very efficiently must be well established before it will be justified to make use of this unique human resource.

How efficient the supply of water as a whole might be, it only can bear fruit when the water is used efficiently on the farmer's level. This brings us to the discussion of the drought resistant plants and modern technology for water use on the micro-scale or field level.

7. Efficient Irrigation Systems

From experience, also shared by FAO (1980), is learned that the three major types of irrigation even when carried out in an efficient way still differ from each other in output because of the shortcomings inherent to each system.

The overall irrigation efficiency Ep for border, sprinkler and drip irrigation is respectively 0.32, 0.45 and 0.61 % from the ideal, which is close to the theoretical approach. In many desert areas, however, the efficiency drops to 0.10 %, especially in the Near East and North Africa where irrigation water is free of charge or only a lump sum has to be paid independently of the amount of water received. Traditionally border irrigation can even lead to complete floodings when close control is lacking.

8. Drought Resistant Plants

Efficiency of water use can be increased by choosing the right crop. Some varieties are much more efficient than others. Plant breeding in the common sense of the word has provided crops having a water efficiency which is 20 % better than the former breeds. The recent acquisitions through genetic engineering are not mentioned here as the new plants are too expensive for the farmers of poor countries.

When the amount of water for plant growth is the limiting factor and not the area which potentially can be irrigated, one often gets a greater benefit by irrigating more land with less water. Under such circumstances not all crops react the same. Therefore the yield response coefficient *ky* of the plant under water stress must be known. This parameter has been developed during recent years in a well documented literature and published by FAO (1977-1980).

The lower the *ky* factor the less the plant suffers when the water availability goes down. A low *ky* factor indicates that the crop is resistant to drought. Low *ky* plants are groundnuts, cotton, grapes, alfalfa, olives, safflower, sorghum, soybeans, sunflower etc. Amongst the medium *ky* ones, following plants can be mentioned: barley, wheat, green bean, cabbages, citrus fruits, melon, peppers, potatoes, tomatoes etc.

9. Salinization as a Major Problem

While irrigating the water penetrates the soil. Its first action is to dissolve the salts. Indeed, one of the characteristics of any desertic soils is its high salinity. In moist soil the pores are filled with the water enriched with the solutes. Due to the capillary rise and the high temperatures the salts migrates with the water to the soil surface where it evaporates and leaves the salt behind.

Salt precipitation near the plants kills the vegetation due to the high osmotic pressure, which means that the majority of the water, both from the plants and the soil, is sucked into the salt. First the plant growth is slowing down, ultimately the plant is killed (see

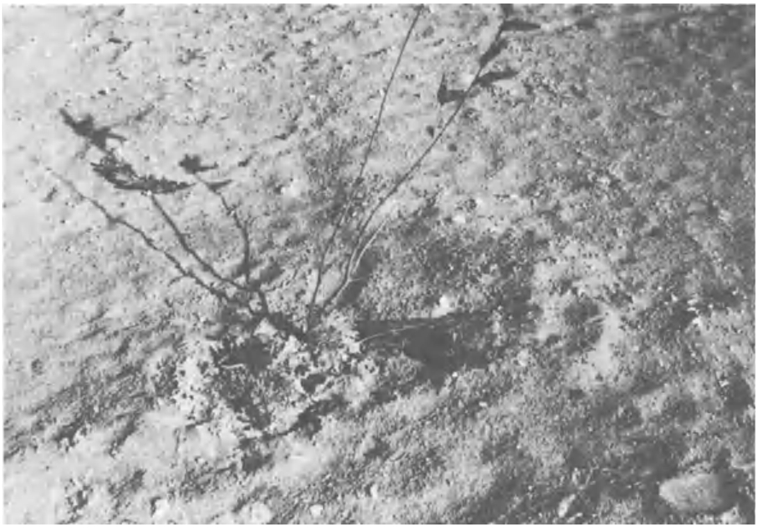


Photo 1. Drip irrigation applied on a desertic sandy soil near Cairo when growing citrus trees. Without soil conditioning, resulting in salt crust formation killing the trees.

Photo 2. With soil conditioning: luxurious growing trees are observed. Evaporation from around the tree is cut avoiding salinisation while adequate water distribution in the root zone is assured as explained in Figure 3.

photos 1 and 2). A new technology recently developed at the State University of Gent has made it possible to overcome this failure.

As mentioned before, drip irrigation is beyond any doubt in many cases one of the most efficient and economic ways of supply water to the plants. Its application is limited because of the risk of salinisation, especially around the plants and the drippers. Therefore special precautions, known as soil conditioning, have to be taken.

In this respect, sandy soils differ in many respects from loamy soils (Figure 3). The pores in sandy soils are larger due to the presence of coarse sandy particles. The water retention capacity is small. Due to gravity forces most of the irrigation water proceeds vertically downwards. There is no lateral suction of water because in large pores the capillary forces are nearly non-existing.

The behaviour of the different soil types is illustrated in Figure 4. The natural infiltrating water profiles in a loamy and a sandy soil are showing a normal and an elongated onion shape respectively. In the case of a sandy soil the water drops move in a narrow beam downwards. In such a case the root system of the plant will only develop in the moist part of the soil. It will be long and elongated with little ramifications. The yield of a plant with such a root is mostly low.

In general it can be said that the more voluminous the root develops the higher the yield will be. Soil conditioning promotes a wide soil moisture front and volume, as shown in Figure 3. That way yields can be doubled.

In Figure 4 on the left the case of a loamy soil is given. Loamy soils are composed of small soil particles. This means a high capillary suction power due to the fine pores present. The pores have a diameter of between 50 and 100 μm. When introduced in such a soil, the water is subjected not only to gravity, promoting a vertical downwards movement, but also to lateral suction. As at the top the soil is drier, the water pull in the pores will be highest. Thus the water moves at the beginning only in the top layer with a priority for lateral movement close to the surface. This water evaporates easily leaving a salt crust. Specific soil treatments are necessary to prevent this.

Soil conditioners have to fulfil a triple purpose:

a. to keep the water in the upper layers where the root system normally develops;
b. to prevent the evaporation of the water close to the surface;
c. to avoid the salt crust formation.

It can be done by spreading cheap synthetic polymers, the so-called soil conditioners, on the surface (Figure 5). Their action is based on the change of the capillary properties starting from the soil surface. To prevent deep infiltration and to fix the water in the root zone another effective water adsorbent must be used. This is done by introducing a powder, being hydrolysed polyacrylamide, known as a hydrogel. In such circumstances it adsorbs $\pm$ 300 times its own weight. It can be mixed at the appropriate depth (root zone) in the soil to retain the water (see Figure 6a and 6b) exactly where it is needed by the plant roots.

Those products were quite expensive some 10-15 years ago, but mass production, even in developing countries made the prices fall. Another important development has been that some waste plastic foils could be recuperated and put into an emulsion. When derived from polyethylene, polypropylene, P.E.G. etc. of which the chemical formulae are given in

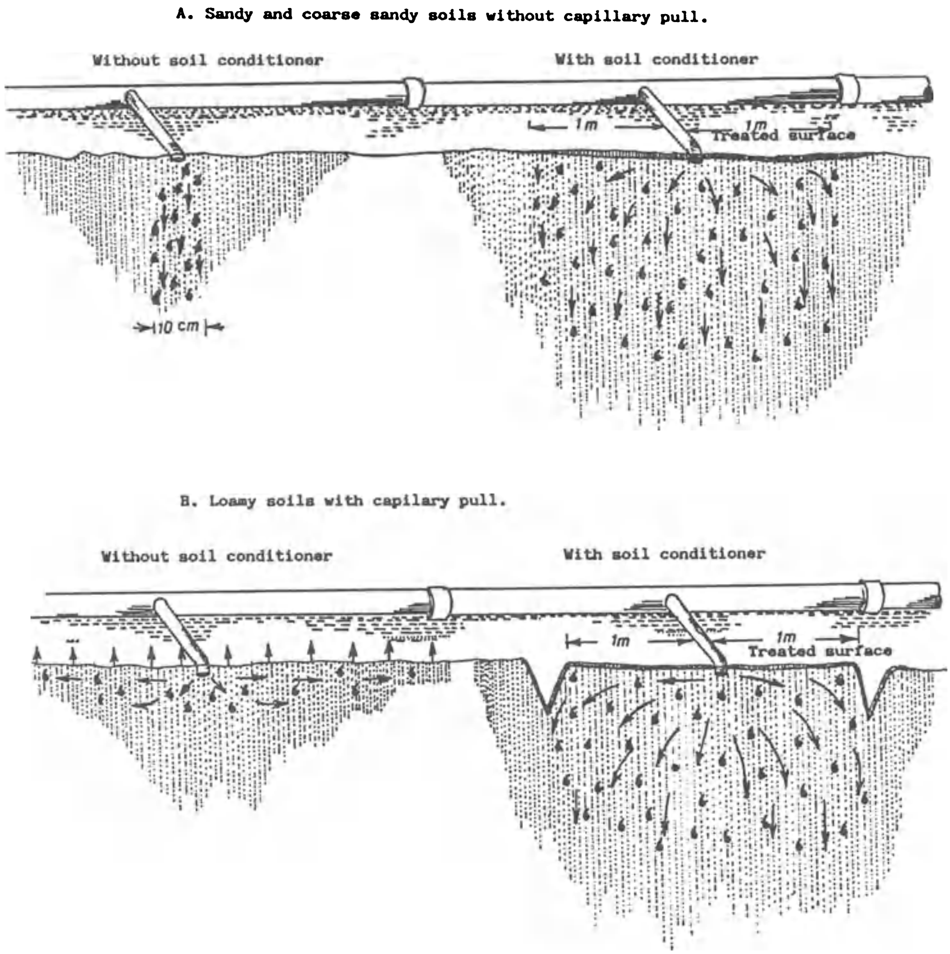


Figure 3. Water infiltration in desertic soils can be manipulated by applying soil conditioners. On sandy soils most effective results are obtained using emulsions of which the hydrophobic and hydrophylic parts get oriented respectively to the atmosphere and to the wet soil. So evaporation from the soil surface is cut and the lateral extension of the water to moisten the root zone is promoted. On heavy soils the emulsions will prevent evaporation as well as salt crust formation.

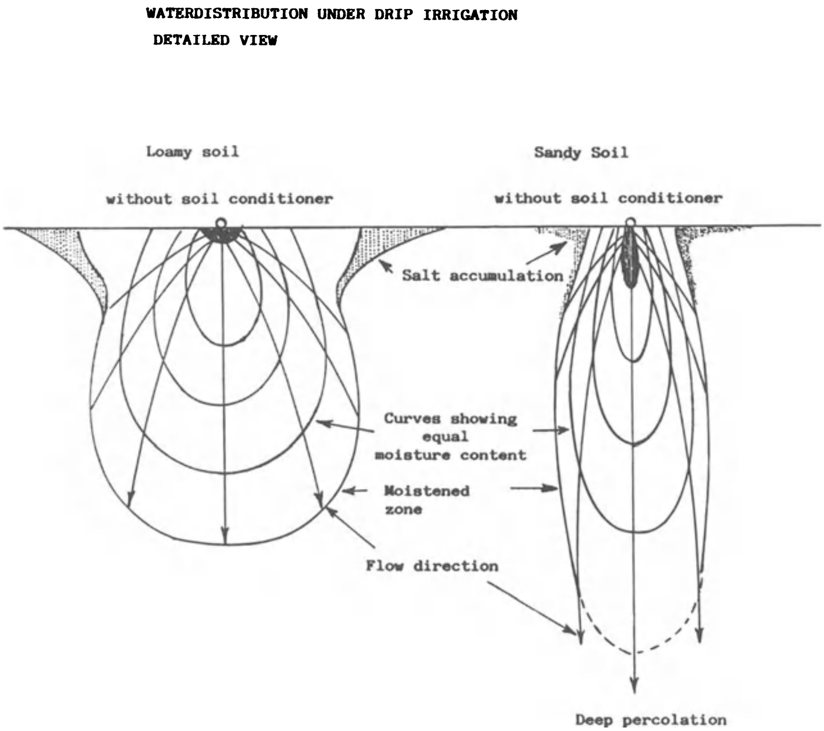


Figure 4. Complements Figure 3. It compares the normal water distribution and salt accumulation in loamy and sandy soils when drip irrigation is applied without soil conditioning.

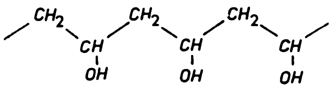
Figure 5, cheap and effective products can be developed. They can be applied around the plants and the drippers to cut the evaporation. They are hydrophobic preventing capillary rise and hence salt crust formation.

Other conditioners mentioned at the top of Figure 5 which can be put into solution are hydrophilic. They can fix relatively high amounts of water. These soil conditioners in combination with chemical fertilizers and pesticides can be mixed together in the plough layer in order to promote good plant growth.

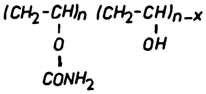
Soil conditioners can be spread over the seeding lines as a mulch using a normal pesticide spraying machine. The polymers, being adhesives, when brought into contact with the soil particles will aggregate them. In surface treatment, the dose is normally 20-40 g active material per m^2. When planting trees these chemicals are mixed in the plant pit to promote water storage in the root zone. A dose of not more than 0.1 % active material by weight calculated on the amount of soil involved is needed to be effective.

The size and depth of the waterfront in the soil profile and the amount of available

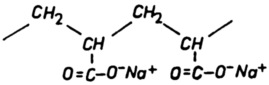
A. POLYMERS SOLUBLE IN WATER : HYDROPHYLIC SOIL CONDITIONERS



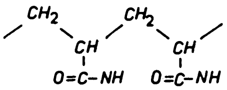
POLYVINYL ALCOHOL (PVA)



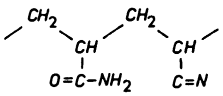
POLYVINYL ALCOHOL
URETHANE STRUCTURE (PVAu)



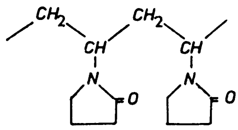
NATRIUMPOLYACRYLATE (SPA)



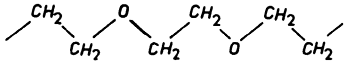
POLYACRYLAMIDE (PAM)



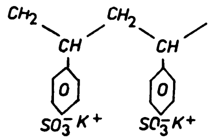
PARTIALLY HYDROLYSED
POLYACRYLONITRIL (HPAN)



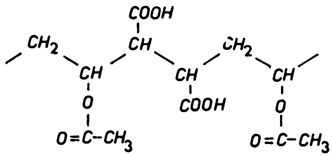
POLYVINYLPYRROLIDON (PVP)



POLYETHYLENE GLYCOL (PEG)

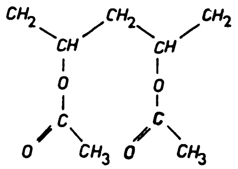


POTASSIUM POLYSTYRENE SULFONATE (PS)

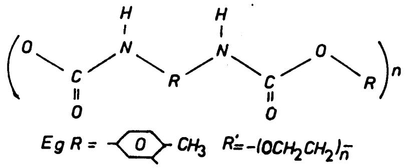


VINYLACETATE MAELIC ACID (VAMA)
COPOLYMER

B. POLYMERS IN WATER-EMULSIONS : HYDROPHOBIC SOIL CONDITIONERS



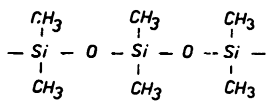
POLYVINYLACETATE (PVAc)



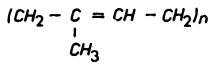
POLYURETHANE

$(CH_2-CH=CH-CH_2)_n$

POLYBUTADIENE (BUT)



POLYSILOXANE



- RUBBER LATEX
- BITUMEN

Figure 5. Formulae of soil conditioners which are the most frequently used with either predominantly hydrophobic or hydrophilic properties.

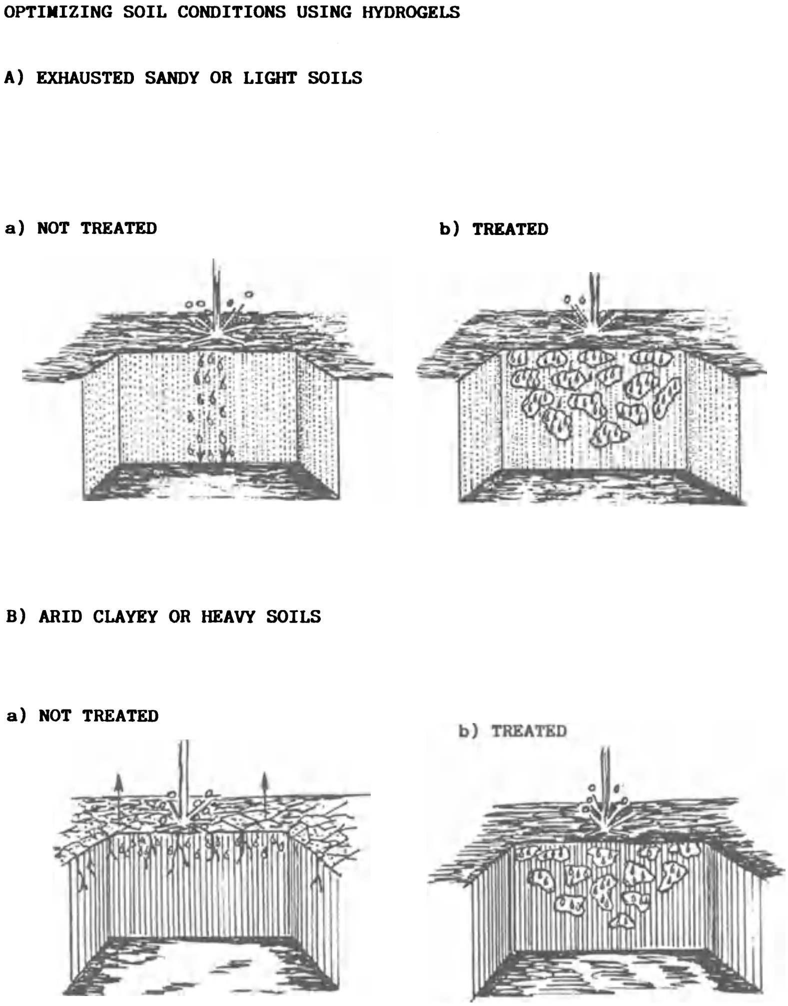


Figure 6. Hydrophilic soil conditioners, called hydrogels, can also be produced and applied in the dry form. The increase in water holding capacity in the root zone is obtained by mixing the product in the soil as illustrated both in a sandy or light soil and in a heavy soil. It shows how deep-percolation can be prevented.

water can be regulated when drip irrigation is applied and the output of the drippers is adjusted. The way it works is shown in Figures 3a and 3b, and in Figures 6a and 6b.

10. Efficient Water Management

From the foregoing it becomes obvious that there exist two major types of polymeric organic chemicals which can interact in two ways on the water distribution in the soil and on the water availability for plant growth. When using hydrogels the powdery chemical is thoroughly mixed with the soil (Figure 6). When water is applied, even in huge quantities, it is adsorbed in the soil profile at the height of the root development. The other type of chemical is hydrophobic. This is broadcasted as a diluted synthetic polymer on the soil surface. It can be either a mulch or a solution mixed superficiously with the soil particles to facilitate their aggregation. In this way slaking, evaporation and salt crust formation are avoided.

When a hydrophilic polymer is applied on the wet surface of a sandy soil, conglomeration and aggregation of the soil particles could also occur. The pore size of the loose soil will diminish, the average diameter will drop from $\pm$ 50 µm to $\pm$ 5 µm. It means that most of the water transmission pores will be replaced by smaller water storage pores. Thus the irrigation water can be retained in the aggregated upper soil layer. As more water is applied by drip irrigation the soil pores will be filled up and a downwards water movement will start. A hemispherical waterfront will develop in the root zone as shown in Figure 3. The depth will depend on the amount of water applied. Deep seepage as normally occurs in untreated soils does not happen because the water is held up by the porous suction in the top layer. As mentioned above the other, more effective but also more expensive, way of avoiding deep penetration is by mixing the hydrogels with the soil.

Measurements on experimental fields in Egypt and Saudi Arabia have shown that approximately 50 % of the irrigation water could be kept in the ground which otherwise would have been lost through evaporation or deep infiltration.

There is still another phenomenon to be mentioned. The water vapour immediately underneath the treated soil layer is subjected to a temperature gradient. The water vapour near the surface has a higher potential than at the cooler but deeper layers. This causes a reflux of the water also known as a distillation-condensation effect in the root zone. The condensed water contains only minute amounts of salt. In this moistened layer situated mostly at a depth of about 15-20 cm a vigourous root growth can often be observed.

In summary, the deep seepage and salt accumulation pattern all too often occurring in the classical irrigation system in semi-arid and arid regions can be mastered and replaced by an economic and efficient water management system with little or no salinization hazards.

11. References

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