SOILS BULLETIN 25

SANDY SOILS

Report of the FAO/UNDP Seminar on
Reclamation and Management of Sandy Soils
in the Near East and North Africa

Nicosia, Cyprus, 3-8 December 1973

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1975

III.6 IRRIGATION OF SANDY SOILS

by

J. P. Baudelaire
Irrigation Sciences Officer
Water Resources and Development Service
Land and Water Development Division
FAO, Rome.

SUMMARY

In irrigation development projects involving sandy soils the irrigation method must be considered very carefully. This paper proposes the best irrigation techniques but even with these the risks of low irrigation efficiencies remain. It is therefore very important that farmers be well informed on special irrigation techniques through a suitable educational programme.

In this paper an analysis is made of the physical characteristics and water-soil relationships of sandy soils, and the various irrigation methods reviewed with recommendations given as to proper water management at field level.

Two important characteristics of sandy soils are their coarse texture and high rate of hydraulic conductivity. An understanding of these characteristics is necessary for the design and operation of farm irrigation systems. These characteristics control the determination of the type of farm irrigation system to design, the size of design, the amount of water necessary for proper utilization of the system and the frequency and amount of irrigation.

In general surface irrigation methods are not the most suitable for sandy soils whether by basin, border or furrow. The high permeability and the low water storage capacity make it very difficult to apply the correct amounts of water. Irrigation of sandy soils may lead to water wastage by deep percolation and low irrigation efficiencies of less than 50 percent. Moreover the yield of crops may also be affected by bad uniformity application. The lowest parts of fields often do not receive enough water to meet their requirements whereas the upper parts are generally over-irrigated. Nutrients are carried away and micro-elements are frequently lacking. Usually, under normal conditions, surface irrigation methods are not recommended for sandy soils.

Nevertheless there exist special cases when these negative aspects may become useful to crops. This is particularly true for irrigation with brackish water where the excess salts brought by the irrigation water are rapidly leached out of the rootzone. No special on-farm measures such as drainage systems may be needed.

Despite what has been said, the irrigation of sandy soils is sometimes inevitable because good arable lands are lacking.

Sprinkler irrigation has built-in features which make it particularly well adapted to sandy soils. Transport of water is by pressure pipes and water losses are low. But perhaps the most interesting feature of sprinkler irrigation is its ability to apply small volumes of water with a very good distribution pattern. Matching water applications to soil water holding capacities is no longer a constraint. Deep water percolation can therefore be controlled to the strict minimum admissible by the method. Furthermore the size of the plots or the depth of the crops have no influence on the application efficiency and crops of any type, deep or shallow-rooted, broadcast or planted in rows, can be irrigated with equal success.

Drip irrigation is one of the latest irrigation methods to be developed. Although it had been known for many years it was only used in very special cases by some horticulturists and nursery gardeners. Its application at the farm level became possible by the extensive use of polyethylene plastics in manufacturing the various components of the equipment. This has reduced its cost which, although rather high, is now acceptable for some crops. Trickle irrigation really started in agriculture less than 10 years ago. The real success of this new method is based on a certain number of advantages which are claimed by the enthusiastic promoters of the method: water saving, higher yields, utilization of brackish waters, manual labour extremely reduced, decreases in diseases, weed control, etc. In fact most of these promising results have been obtained in experimental conditions by highly qualified specialists. Comparative field trials are still too few to say in what proportion these advantages are applicable to large scale irrigation. The method is still in its initial stages and many developments are expected in the near future.

A well designed irrigation scheme may not yield the expected returns if water is not managed in the proper way by farmers. This may be even more true in the case of sandy soils for which irrigation must be handled with special care. The human aspect is often unduly disregarded during the planning period whereas it plays a decisive part during the whole lifetime of a project. It is therefore necessary to provide these farmers with the minimum knowledge that they need so badly. This of course can only be done by an intensive education programme of demonstrations, advice, rewards, etc., carried out by a well organized extension service. The extension workers to be efficient should receive special training in the irrigation of sandy soils based on a very good knowledge of the local soil conditions.

6.1 INTRODUCTION

In irrigation development projects involving sandy soils the irrigation method must be considered very carefully. This paper proposes the best irrigation techniques but even with these the risks of low irrigation efficiencies remain. It is therefore very important that farmers be well informed on the special irrigation techniques through a suitable educational programme.

In this paper an analysis is made of the physical characteristics and water-soil relationships of sandy soils, and the various irrigation methods reviewed with recommendations given as to proper water management at field level.

6.2 WATER-SOIL RELATIONSHIPS OF SANDY SOILS

Two well known physical features of sandy soils are their coarse texture and their high rate of permeability. Other features that play an important part in irrigation are the pore space, the bulk density and the water content.

6.2.1 Texture

The distribution of the soil particles according to their size is called the texture. Sand is usually defined as particles having a diameter between 0.05 and 1.00 mm. If the amount of particles within this range is greater than 50 percent the soil is said to be sandy. According to the exact percentages of sand and other particles contained in a sandy soil its texture will vary from sandy-clay to coarse sand. The texture of sandy soils has a very important influence on the infiltration rate, the water holding capacity and consequently on its value for irrigation. Since, generally, the more loam and clay contained in the soil the better it will be for irrigation, a mechanical analysis is a necessary tool for soil classification. Coarse soils are easily eroded by running water which is one of the obstacles to successful surface irrigation.

6.2.2 Infiltration Rate

The infiltration rate is the velocity at which water percolates into a soil and usually decreases the longer water is in contact with the soil. It will reach a relatively steady value equal to the permeability or hydraulic conductivity of water through the soil. This variation of infiltration rate with time differs from one type of soil to another. In the case of sandy soils the final rate is reached rapidly and is usually high.

Sandy soils have high infiltration rates varying for sandy clay and sandy loam from 4 to 25 cm/h, but in very permeable sandy soils values as high as 100 to 400 cm/h are easily reached. High final infiltration rates are responsible for important water losses both in the conveyance systems and in the fields. Soils having a final infiltration rate of 10 cm/h and above are generally not recommended for surface irrigation systems. In other words, to keep the conveyance and application efficiencies at an acceptable level the length of the ditches and the size of the fields may be too small for proper cropping. A 30 l/s flow could irrigate no more than 1 080 m^2 at any one time. The uniformity of application will be poor if the fields are large since upper parts would receive more water than the lower ones. High infiltration rates may be an important constraint to efficient surface irrigation schemes.

High infiltration rates also have an action on the soil structure in that often the clay particles contained in the upper layers are conveyed to deeper layers where they accumulate and form a less permeable horizon. This horizon may impede the deep percolation of excess water coming from rain or over-irrigation and may form a perched water table which will require field drainage.

6.2.3 Porosity and Apparent Specific Gravity

The porosity or pore space is that space between the soil particles which is equal to the ratio of the volume of voids either filled with air or with water to the total volume of soil, including air and water. The porosity or pore space of sandy soils is less than for clay soils.

The apparent specific gravity or bulk density is the ratio of the weight of a given volume of dry soil, dry space included, to the weight of an equal volume of water. The apparent specific gravity varies with soil types as does the porosity. Mean and extreme values are indicated in the following table abstracted from the book "Irrigation Principles and Practices" by Israelsen.

Table 1 APPARENT SPECIFIC GRAVITY AND PORE SPACE

Soil Texture	Apparent Specific Gravity	Pore Space
Sandy		
mean	1.65	38
extremes	1.55-1.80	32-42
Sandy loam		
mean	1.50	43
extremes	1.40-1.60	40-47

The more sandy a soil the higher is its apparent specific gravity and the lower is its pore space. Thus sandy soils which are often designated by farmers as "light soils" are in fact the ones that weigh the most per unit volume. The term "light" refers to their ease in working with agricultural implements.

6.2.4 Water Content and Water Holding Capacity

The water content of a soil depends on the amount of water stored in the pore space. Since sandy soils do not have a very large total pore space, their water content will never be very high. The water content can be expressed either as a percentage on a dry weight basis or as a percentage on a volume basis. The moisture content on a dry weight basis is equal to the ratio of the weight of water contained by a soil at field capacity to the weight of this same soil after having been dried in an oven at a temperature of 105°C. The moisture content on a volume basis is equal to the ratio of the volume occupied by the water stored in the pore space to the total volume of the soil.

Field capacity (FC) is defined as the percentage of water retained in the pore space of a soil after the excess water from an irrigation has percolated to deeper layers. In practice the field capacity is determined one or two days after an irrigation.

Permanent wilting point (PWP) is defined as the percentage of water still remaining in a soil once the plants are no longer able to extract sufficient moisture to meet their needs.

The available moisture in percentage is then the amount of water which is available between these two values.

This relation can be converted to a depth of water available in soil which is usable in determining quantitative water requirements of individual crops grown in specific soils and is called the readily available water.

In irrigation practice it is not recommendable to wait for the soil water to reach the permanent wilting point before replenishing the soil reservoir. In this way the plants will not suffer from an eventual lack of water. In principle, water applications should never be greater than the readily available water as any excess will automatically be lost by deep percolation.

The following table adapted from "Irrigation Principles and Practices" by Israelsen gives some practical values of water applications in sandy soils.

Table 2 MOISTURE CONTENT AND PRACTICAL WATER APPLICATIONS

Soil Texture	Field Capacity %	Permanent Wilting Point %	Practical Water Application for a soil depth of 0.5 m mm	1.0 m mm
Sandy loam				
mean	14	6	45	90
extremes	10-18	4-8	35-55	70-110
Sandy				
mean	9	4	30	60
extremes	6-12	2-6	22-37	45-75

The conclusion can thus be drawn that deep-rooted crops are better for sandy soils than shallow-rooted ones.

6.3 IRRIGATION METHODS

6.3.1 Surface Irrigation

In general surface irrigation methods are not the most suitable for sandy soils whether by basin, border or furrow. The high permeability and the low water storage capacity make it very difficult to apply the correct amounts of water. Irrigation of sandy soils may lead to water wastage by deep percolation and low irrigation efficiencies of less than 50 percent. Moreover the yield of crops may also be affected by poor uniformity of application. The lowest parts of fields often do not receive enough water to meet their requirements whereas the upper parts are generally over-irrigated. Nutrients are carried away and micro-elements are frequently lacking. Usually, under normal conditions, surface irrigation methods are not recommended for sandy soils.

Nevertheless there exist special cases when these negative aspects may become useful to crops. This is particularly true for irrigation with brackish water where the excess salts brought by the irrigation water are rapidly leached out of the root-zone. No special on-farm measures such as drainage systems may be needed. Irrigation with waters containing up to 4 000 ppm on oasis sandy soils in Tunisia has been reported with no damage to crops. Another special case would be underground irrigation by perfect control of the water table, made possible in sandy soils by their high transmissivity. But this type of irrigation requires the construction of drainage canals or pumping wells and would increase the initial investment.

Despite what has been said, the irrigation of sandy soils is sometimes inevitable because good arable lands are lacking. The following recommendations should then be considered: First of all the water distribution system should either be lined or piped as indicated in the previous paper (III.5) and should be able to deliver water at very short intervals. The smaller canals will therefore have to be increased in size and so will be the cost of the systems. The size of the fields should be reduced and the streams available at the headgates be large enough to enable a quick filling of the plots.

The best irrigation method would be by small basins of only a few quare metres in size (10 to 20 m^2). The main drawback of this method is its high requirement in manual labour, first to prepare the small basins and then to irrigate them one after the other. This method also precludes any kind of mechanization. A way of further reducing the water losses within the farm would be to convey the water from the headgate to the basins by using light aluminium or plastic pipes laid on the soil like those utilized in hand-move sprinkler irrigation systems. This way of irrigating is sometimes called the "hose basin irrigation method". It is probably the best adaptation of surface irrigation to sandy soils but it also increases the cost.

Finally, when a water table is present it is absolutely essential in a large scheme to keep close track of its fluctations. Should there be a tendency to rise, a drainage system might have to be installed. This particular aspect will be dealt with in the following paper (III.7)

6.3.2 Sprinkler Irrigation

Sprinkler irrigation has inherent features which make it particularly well adapted to sandy soils. The transport of water is by pressure pipes and water losses are low. But perhaps the most interesting feature of sprinkler irrigation is its ability to apply small volumes of water with a very good distribution pattern. Matching water applications to soil water holding capacities is no longer a constraint. Deep water percolation can therefore be controlled to the strict minimum admissible by the method. Furthermore the size of the plots or the depth of the crops have no influence on the application efficiency and crops of any type, deep or shallow-rooted, broadcast or planted in rows, can be irrigated with equal success.

These features only become a reality if the sprinkler irrigation system is designed and managed properly. Some engineering aspects are dealt with in the following paragraphs.

First of all, the designer should take advantage of the high infiltration rates of sandy soils and use high application intensities. This will reduce cost which is higher in sprinkler than in surface irrigation. But high application rates for a small water holding capacity imply more frequent shifts of lateral lines, so in order not to lose the benefits of high application rates by an increase in the labour requirements, it is recommended that the shifts be limited to 4 per day or the system placed on wheels.

The application efficiency should be considered about 70 percent to account for losses in the field and in the atmosphere.

The spacing of sprinklers has little influence on the irrigation of sandy soils. However, larger spacings of 18 x 18 m or 24 x 24 m are less expensive than smaller ones of 12 x 12 m. Spacing limitations will be dictated mainly by atmospheric conditions. If the site is windy it is better to use closer spacings either rectangular 12 x 18 m, the 12 m side being perpendicular to the main wind direction, or 12 x 12 m.

The periods of irrigation per day should be as long as possible to reduce the investment costs. The fact that shifting laterals during the night is very difficult must be considered. Since the frequency of lateral shifting is high in sandy soils practically, it will not be possible to envisage night irrigation. Irrigation time will thus be limited to the daylight hours plus the duration of one position which can be started just before sunset and stopped during the night. The effective duration of the irrigations take into consideration the time required for shifting the lateral lines and, eventually, the time during which the installations would have to be stopped because of high wind velocities. It is to be borne in mind here that irrigations should be stopped when the wind velocity is above 5 mi/s (18 km/h). Above this figure water losses caused by wind drift are very high and application uniformity and efficiency are considerably reduced. If the number of hours left for operation is too small it may then be necessary to consider the plantation of windbreaks. In practice the number of effective irrigation hours per day should not be under 12.

Operational pressure of the sprinklers depends essentially on the spacings. Large spacings require higher pressures in the magnitude of 4 to 5 bars. In sites where energy is expensive and where water must be pumped from deep wells high pressures are not economical. Medium pressures of 2 to 3 bars are the most commonly used. Low pressures of 1.5 - 2 bars can be used in conjunction with small spacings for vegetables or in orchards. Irrigation under the leaves is always recommended when the irrigation water is brackish.

The frequency of irrigation is determined by the low water holding capacity of sandy soils. Rotations will therefore be relatively high, from a few days to a week, depending on the soil characteristics and the root depth of the crop to be irrigated.

All sprinkler irrigation systems can be improved in order to reduce the manual labour requirements. The field equipment may be mobile, semi-permanent or completely permanent; motorization of shifts can be introduced by using tractors and trailers, or self-propelled lines. Automation of irrigation may also be introduced by the use of automatic metering valves or even computer monitoring but all these improvements increase the installation costs considerably. Their use will be limited to high return crops or to special cases where insufficient manual labour is a major constraint. In governmental projects it is better to start the irrigation developments with the simplest equipment which can be well handled and understood by the farmers and to let each farmer improve his own system as his financial capabilities increase.

6.3.3 Drip Irrigation

Drip irrigation is one of the latest irrigation methods to be developed. Although it has been known for many years it was only used in very special cases by some horticulturists and nursery gardeners. Its application at the farm level became possible by the extensive use of polyethylene plastics in manufacturing the various components of the equipment. This reduced its cost which, although rather high, is now acceptable for some crops. Trickle irrigation really started in agriculture less than 10 years ago. Israel already claims to have 10 percent of its arable land (around 1 500 ha) irrigated in this way. At present the method is developing quite rapidly, especially in the U.S.A., Australia, South Africa and Mexico. Other countries have shown a definite interest in the method, mainly Senegal (200 ha in just one farm), Italy, U.K., France, Spain, Tunisia, Lebanon, and probably many other countries. Several FAO projects have experimental plots equipped with drip irrigation. These are in Senegal, Spain and Tunisia where the method is going to be tested on olive trees. The real success of this new method is based on a certain number of advantages which are claimed by the enthusiastic promoters of the method: water saving, higher yields, utilization of brackish waters, manual labour extremely reduced, decreases in diseases, weed control etc. In fact most of these promising results have been obtained in experimental conditions by highly qualified specialists. Comparative field trials are still too few to say in what proportion these advantages are applicable to large scale irrigation. The method is still in its initial stages and many developments are expected in the near future. The Americans are developing various systems among which is one without drippers consisting of a double wall perforated pipe; the French are promoting a system in which the water is distributed into a large furrow by a perforated pipe; the Italians are experimenting some very ingenious devices. Nevertheless the method most widely used consists of small tubes along which are the drippers (or tricklers, or emitters).

The dripper is a small device that allows the water to discharge from a lateral supply line at a very low and constant rate, from 2 to 10 l/hour. As water flows out of a dripper it moistens the soil surface in a circle and the underneath layers according to a bulb shaped volume. The spacing of the drippers along a line should permit the various wetted bulbs to come into contact with one another. The flow and spacing of drippers are determined by field tests.

In sandy soils the wetted bulbs under the drippers are narrow and deep. Since the wetted bulbs should be in contact with one another along the lateral lines their number will be high. The cost of equipment, which is proportional to the length of pipes and number of drippers, will then be high and in the magnitude of US $ 1 700 to 2 000 per ha not including the pumping plant. These systems usually operate at a low pressure of 1 to 1.3 bars.

The spacing between the lines will depend on the type of crops irrigated. If the rows are very close, such as in the case of vegetables, a line for every two rows may be sufficient. On the contrary if the rows are very far apart, such as in the case of orchards, it may be necessary to install two or more lines per row of trees. In any case drip irrigation is most convenient for row crops.

The water savings come from the fact that there is a non-irrigated zone in between the lines. But the consumptive use of a crop being a factor independent from the type of irrigation used the water savings are not as high as often claimed. In fact deep percolation may occur along the lines and irrigationists recommend designing the systems with an 80 percent application efficiency.

The irrigation water must be filtered to prevent the clogging of drippers. Brackish water may be used because the roots of the plants develop inside the wetted bulb where the salt concentration stays constant and equal to that of the irrigation water itself. The salts tend to accumulate in the outer parts of the wetted bulb and often white circles denoting the presence of salt can be seen on the soil surface. The excess salts must be leached either in a natural way by the winter rains or artificially with a spare sprinkler irrigation set when rain is not sufficient.

6.4 IRRIGATION EDUCATION

A well designed irrigation scheme may not yield the expected returns if water is not managed in the proper way by farmers. This may be even more true in the case of sandy soils for which irrigation must be handled with special care. The human aspect is often unduly disregarded during the planning period whereas it plays a decisive part during the whole lifetime of a project. Most farmers have no precise idea of the relationships existing between the consumptive use of water, the rate of infiltration, the water storage capacity, etc., in a soil. Their only guide lies in traditions, instinct and sometimes wrong beliefs. They know when the plants need to be irrigated because they see them wilt but they are not too versed in the idea of how much is needed or how much is applied. Errors leading to over-irrigation and wastage of water occur just because of lack of knowledge. It is therefore necessary to provide these farmers with the minimum knowledge that they need so badly. This of course can only be done by an intensive educational programme comprising demonstrations, advice, rewards, etc., carried out by a well organized extension service. The extension workers to be efficient should receive special training in the irrigation of sandy soils based on a very good knowledge of the local soil conditions.

6.5 CONCLUSION

Sandy soils have a low pore space and a high infiltration rate. The consequences of these two features on irrigation systems and methods are of paramount importance.

The low pore space is responsible for a low water holding capacity. Consequently the frequency of irrigation and the labour requirements are high independently of the irrigation method used. Labour requirements can be reduced but the initial cost of equipment is then considerably increased.

The high infiltration rates make surface irrigation very difficult as an important task is to avoid losses when applying water to the fields. The adaptation of surface irrigation, when possible, requires higher investment costs for increased length and size of canals, canal lining, large number of small plots and eventually special on-farm equipment.

On the contrary high infiltration rates have little influence on sprinkler irrigation. This method can therefore be considered as the best for sandy soils. It will lead to acceptable efficiencies if properly designed and managed.

Drip irrigation is a promising method but its cost is still quite high. It is recommended to set up field trials before embarking on large scale developments with drip irrigation.

In any case irrigation of sandy soils requires a good deal of knowledge and skill. Guidance should be provided to farmers by a well organized irrigation education programme.