IRRIGATION AND DRAINAGE PAPER 36

localized irrigation –

FOOD AND AGRICULTURE ORGANIZATION
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localized irrigation – design, installation, operation, evaluation

by

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PREFACE

This publication has been prepared as a contribution to the rapidly developing field of new irrigation techniques within the scope of localized irrigation. Much active research is being conducted on the subject in various parts of the world. As new information becomes available, techniques already developed over the past decade may be modified or refined and new ones are being developed. Consequently, this publication cannot be expected to be a comprehensive treatise on all aspects of localized irrigation. However, it does seek to provide guidelines on promising techniques for practical application in the field.

This first edition has been prepared with a view to attracting expert comments and further contributions which would be considered for incorporation into an updated and possibly more comprehensive publication. It is hoped that the publication will serve as a manual for the guidance of experts, counterparts, government officers and others concerned with the planning, design and operation of projects using new techniques in member countries.

Sincere thanks are due to all those individuals and organizations who have assisted in the preparation of this edition through advice or contributions, and in particular to: Dr. G.A. Jobling of Australia; Mrs. M. Decroix, CTGREF, Aix-en-Provence, France; Mr. J. Keller, University of California; Mr. I-pai Wu, University of Hawaii; and to the Editor, Mr. I. Constantinesco of England.

Comments and suggestions for improvement of this publication will be welcome and should be forwarded to:

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LIST OF MAJOR SYMBOLS AND ABBREVIATIONS

ET_o	reference crop evapotranspiration
ET_{crop}	crop evapotranspiration
E_{pan}	Class A pan evaporation
k_c	crop coefficient
k_p	pan coefficient
k_r	ground cover reduction factor
k_s	water storage efficiency coefficient
GC	ground cover
E_a	irrigation efficiency
E_u	uniformity of application coefficient
PIR	peak irrigation requirement
L_r	leaching component
R	water received by the plant from sources other than irrigation
P	percentage of wetted area
S_e	spacing between distributors
S_ℓ	spacing between laterals
IA_n	maximum amount of water that can be applied per irrigation
Z	depth of the root zone
d_m	allowed moisture depletion
IR_n	net irrigation requirement
IR_g	gross irrigation requirement
q_d	discharge of the distributor or group of distributors
I_d	operation period for a distributor
I_i	interval between irrigations
Q_s	system capacity
U	quality of operation - Clement's formula
H	operating pressure
ΔH	friction loss
Δh	minor friction loss
CV_f	manufacturer's coefficient of variation of a distributor
$\sigma_f(q)$	standard deviation of discharges of distributors
M_r	manufacturer's discharge ratio
F	inline discharge coefficient
L	relative friction of a distributor on a lateral
H(L)	pressure at the location L
SDR	specific discharge rate
H(M,L)	pressure at a relative position L and M

H_o	outer chamber pressure in twin-wall
H_i	inner chamber pressure in twin-wall
q_o	discharge from the outer orifice in twin-wall

LIST OF CONVERSION FACTORS

MULTIPLY	BY	TO OBTAIN
acres	4.047×10^{-1}	hectares
acres	4.356×10^{4}	square feet
acres	4.047×10^{3}	square metres
acre-feet	4.356×10^{4}	cubic feet
acre-feet	3.259×10^{5}	gallons
atmospheres	3.390×10^{1}	feet of water (at 4°C)
atmospheres	1.033	kilograms/square centimetre
atmospheres	1.033×10^{1}	metres of water (at 4°C)
atmospheres	1.470×10^{1}	pounds/square inch
centimetres	3.937×10^{-1}	inches
centimetres/second	1.969	feet/minute
centimetres/second/second	3.281×10^{-2}	feet/second/second
cubic centimetres	6.102×10^{-2}	cubic inch
cubic centimetres	1.000×10^{-3}	litres
cubic feet	2.832×10^{-2}	cubic metres
cubic feet	7.481	gallons
cubic feet	2.832×10^{1}	litres
cubic feet/minute	4.720×10^{-1}	litres/second
cubic feet/second	4.488×10^{2}	gallons/minute
cubic inches	1.639×10^{1}	cubic centimetres
cubic inches	4.329×10^{-3}	gallons
cubic metres	3.531×10^{1}	cubic feet
cubic metres	2.642×10^{2}	gallons
feet	3.048×10^{-1}	metres
feet/second	3.048×10^{-2}	metres/second
feet of water	2.950×10^{-2}	atmospheres
feet of water	3.048×10^{-2}	kilograms/square centimetre
feet of water	4.335×10^{-1}	pounds/square inch

MULTIPLY	BY	TO OBTAIN
feet/minute	5.080×10^{-1}	centimetres/second
feet/second/second	3.048×10^{1}	centimetres/second/second
feet/second/second	3.048×10^{-1}	metres/second/second
gallons	1.337×10^{-1}	cubic feet
gallons	2.310×10^{2}	cubic inches
gallons	3.785×10^{-3}	cubic metres
gallons	3.785	litres
gallons/minute	2.228×10^{-3}	cubic feet/second
gallons/minute	6.308×10^{-2}	litres/second
hectares	2.471	acres
hectares	1.076×10^{5}	square feet
inches	2.540	centimetres
inches	2.540×10^{4}	microns
kilograms	2.205	pounds
kilograms/sq. centimetre	9.678×10^{-1}	atmospheres
kilograms/sq. centimetre	3.281×10^{1}	feet of water
kilograms/sq. centimetre	1.422×10^{1}	pounds/square inch
kilograms/hectare	8.922×10^{-1}	pounds/acre
kilograms/litre	1.198×10^{-1}	pounds/gallon
litres	1.000×10^{3}	cubic centimetres
litres	3.531×10^{-2}	cubic feet
litres	6.102×10^{1}	cubic inches
litres	2.642×10^{-1}	gallons
litres/second	1.585×10^{1}	gallons/minute
litres/hour	2.642×10^{-1}	gallons/hour
metres	3.281	feet
meters of water	9.681×10^{-1}	atmospheres
meters of water	1.422	pounds/square inch
metres/second	3.281	feet/second
metres/second/second	3.281	feet/second/second
microns	1.000×10^{-6}	metres
microns	1.000×10^{-3}	millimetres
microns	3.937×10^{-5}	inches
millimetres	1.000×10^{3}	microns
pounds	4.536×10^{-1}	kilograms
pounds/acre	1.121	kilograms/hectare
pounds/gallon	1.198×10^{-1}	kilograms/litre
pounds/square inch	6.804×10^{-2}	atmospheres

MULTIPLY	BY	TO OBTAIN
pounds/square inch	2.307	feet of water
pounds/square inch	7.031×10^{-2}	kilograms/sq. centimetre
pounds/square inch	7.031×10^{-1}	metres of water
square feet	2.296×10^{-5}	acres
square feet	9.294×10^{-6}	hectares
square feet	9.294×10^{-2}	square metres
square inches	6.452×10^{2}	square millimetres
square metres	2.471×10^{-4}	acres
square metres	1.076×10^{1}	square feet
square millimetres	1.550×10^{-3}	square inches
temperature (^{o}C) + 17.780	1.800	temperature (^{o}F)
temperature (^{o}F) - 32.000	5/9	temperature (^{o}C)

1. INTRODUCTION

1.1 CLASSIFICATION OF WATER DISTRIBUTION SYSTEMS

Water distribution systems for irrigation at the field level may be broadly classified into two kinds as follows:

(i) Systems which cause more or less uniform wetting of all the soil in the field irrespective of the organization of the crop (e.g. broadcast or in lines). These are subdivided into:

  (a) underground systems which control the level of the water table;

  (b) systems which supply water to the surface of the soil, either by gravity (as in flood or border irrigation) or by means of overhead pressurized pipes (as in sprinkler irrigation).

(ii) Systems which cause wetting of only part of the soil in the field. These are also subdivided into:

  (a) underground systems using low discharge piping (subsurface irrigation);

  (b) surface application systems, either by gravity (as in basin or furrow irrigation) or by overhead pressurized pipes.

1.2 DEFINITION OF LOCALIZED IRRIGATION

Localized irrigation comes under the umbrella of systems which cause wetting of only part of the soil in the field, but the term refers in particular to systems which cause wetting of only that part of the soil at the base of the plant (the plant root zone).

This paper deals with specific systems of localized irrigation which have been developed over the past 15 years or so. The essential characteristics of these systems are slow and low volume application of water and fertilizers is localized in the plant root zone, through distribution devices such as orifices, nozzles, microtubes, porous pipes, etc., whether organized under or above the soil surface.

In Table 1 the terminology used in this paper is placed in context with the wide range of terminology used for various components of localized irrigation in different countries.

Table 1 TERMINOLOGY

Component	Term used in this text	Terms used elsewhere
The method and the different systems	Localized irrigation	Trickle irrigation, drip irrigation, daily flow irrigation, drop irrigation, sip irrigation, diuturnal irrigation, micro-irrigation *
Similar systems but with laterals and the distributors all underground	Subsurface irrigation	Sub-irrigation, trickle irrigation, drip irrigation, drop irrigation
Discharge unit which delivers water at a set rate to the base of the plant	Distributor	Whisker or spaghetti (for microtube), emitter, dripper, dropper, outlet, trickler
Pipeline which runs along the line of plants and which has distributors attached at required intervals	Lateral	Dripper line, drip irrigation line, application pipe
Pipeline which carries water to a set of laterals	Submain	Header line, manifold, secondary
Pipeline carrying water from supply to the submain	Mainline	
Tank for injecting dissolved nutriment into water supply	Nutriment tank	Fertilizer tank

* The term "localized irrigation" is used in this text; however, the term recommended by the International Commission on Irrigation and Drainage is "micro-irrigation", while ASAE has selected the denomination "trickle irrigation".

1.3 BRIEF HISTORICAL DEVELOPMENT

Localized irrigation was first used in glasshouses in England in the late 1940's and in open fields in Israel in the 1950's. Its commercial importance grew in the 1960's following development work in Israel and the introduction of relatively cheap plastic pipes.

Early field work was concentrated in desert areas where conventional surface or sprinkler irrigation systems were unsatisfactory because of the sandy soils and saline water. Under these conditions localized methods showed very encouraging results compared to surface or sprinkler systems. In addition, interest was aroused in localized irrigation for consideration as an alternative to conventional methods on its own merits.

Areas under localized irrigation are increasing rapidly. A worldwide survey carried out in 1975[1] showed that the total area under localized irrigation amounted to 270 297 acres (109 389 ha). The previous 1974 survey showed a total area of 143 006 acres (57 874 ha). The estimate for the year 1980 is about 860 000 acres (348 042 ha).

The conclusion after 15 years of research and field trials is that localized irrigation can provide a practical alternative to long-established methods of surface and sprinkler irrigation. When properly designed and managed, localized irrigation is probably the most efficient in terms of water application and distribution and appears to be an ideal way of supplying plants with nutriments as well. However, its advantages and disadvantages have to be weighed against those of conventional surface and sprinkler irrigation in each particular case. The final decision will most likely be based on the net return versus total installation and running costs.

1.4 EXAMPLE OF A LOCALIZED IRRIGATION SYSTEM

Figure 1 shows the basic components of a localized irrigation system. The components of the system are as follows:

(i) A supply of water under appropriate pressure. A suction filter may be necessary if the source of supply is a farm dam or river which contains organic matter or foreign bodies but is not needed for relatively clean supplies. The pump is usually centrifugal, but for small systems a piston pump is quite suitable. Water may also be provided by a collective distribution network.

(ii) The "control head", connected to the water supply, to regulate the pressure and amount of water applied, to filter the water and to add nutrients. Sometimes additional pressure controls and secondary filters are located at the entrance of the laterals or submain.

A tank is generally used to add soluble nutriment, especially nitrogen. The tank is a small pressurized vessel with an inlet and outlet. A portion of the flow is diverted through the tank, and water plus nutrient in solution is fed back into the mainline. A good quality primary filter is essential for all "control head" installations. A sand/gravel filter with valves for back-washing is the best, but for clean supplies a mesh filter might be sufficient. When the water is heavily loaded with sand, special filters, such as the vortex type, can be installed.

(iii) The mainline connects the different submains to the water source. It is made of asbestos cement, rigid PVC, or galvanized steel pipe similar to main lines used for conventional sprinkler irrigation. For small installations high density PE_h[2] can also be used.

(iv) The submain supplies the laterals on one or both sides. It is either of medium density polyethylene (PE) or of rigid PVC (Polyvinyl chloride).

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[1] Cooperative Agricultural Extension, University of California, San Diego County, 1975.

[2] PE_h : Polyethylene high density PE_b : Polyethylene low density

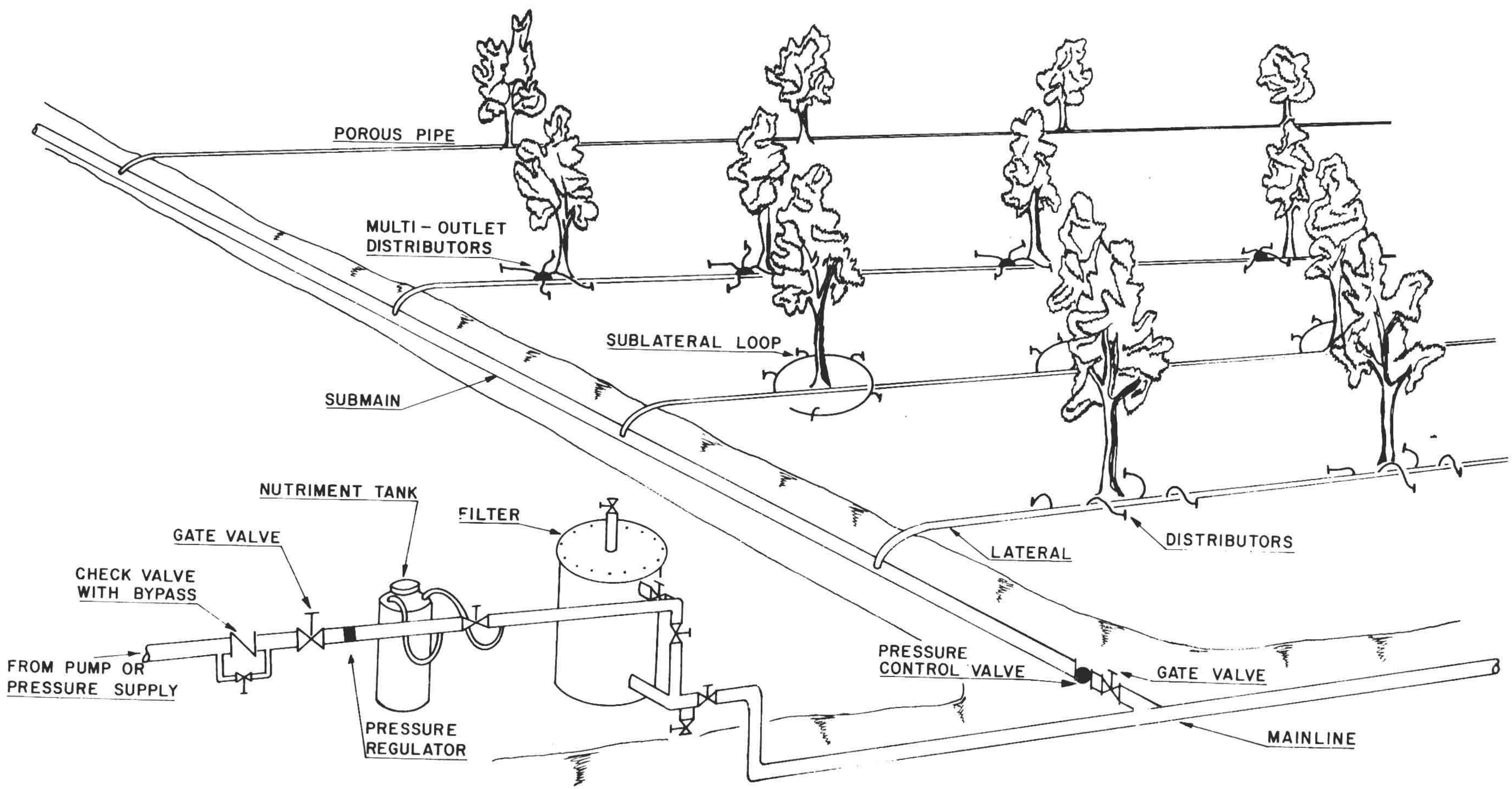

Fig. 1 Basic components of a localized irrigation system

(v) The lateral is almost always of low density PE. Some systems, however, have been installed using small idameter rigid PVC. Distributors are fixed at a predetermined spacing on the laterals or near the trees in the case of orchards. Other types of lateral combine conveyance of the water as well as distribution. These include porous and perforated pipes (single or double walls).

(vi) The distributor is the heart of the system from which the water drips or oozes at a constant low discharge and at atmospheric pressure. It can be a dripper, a microtube, a nozzle or one of the many different types of commercially manufactured outlets.

Most localized irrigation systems are permanent installations but a few are portable, either to serve seasonal crops or to cover a large crop area with a limited amount of equipment.

1.5 ADVANTAGES AND PROBLEMS OF LOCALIZED IRRIGATION

1.5.1 Advantages

(i) Easier management

One undisputed advantage is that localized irrigation does not impede other farm operations. For example, spraying, harvesting, pruning, etc., can be done at the same time as the watering. This is a great advantage in orchards and vineyards. Many farmers now using this technique rate "management" or "access to the field at all times" as the main advantage.

(ii) Reduction in labour

There is a saving in labour compared to conventional sprinkler or surface irrigation methods. This is most important in countries where farm labour is scarce and expensive. The system can in fact operate with very low labour input, but only if it is well designed, correctly installed, and the water supply is clean or well filtered.

(iii) Control over water and nutriments

The amount of water and nutriments and the frequency of application can be controlled very finely. Plants need never be stressed unless deliberately. This ability to supply controlled amounts of water and nutriments direct to the plant roots increases growth and vigour of young plants, and should help to increase yields of mature plants. However, not more than 10-20 percent increase in yield over efficient conventional systems may be expected.

Supplying water direct to the roots through a closed-circuit system saves water. This is of direct benefit in areas where the water supply is limited and/or expensive. But spectacular water savings should not be expected. There are localized irrigation systems which are clearly under-irrigated because insufficient water is used. It might be expected that a localized system would use 20-30 percent less water compared to a well managed sprinkler or surface irrigation system; perhaps up to 50 percent compared to an inefficient surface system. However, savings of the order of only 5 percent have been recorded for some inefficiently operated localized systems.

(iv) Easier control of pests and weeds

Because the foliage and soil surface are not wetted and because there is access to the field at all times, a localized system allows much easier, more efficient and economic control of pests and weeds.

(v) Possible use of saline water

A system applying water frequently enables the soil moisture tension to be kept very low. Thus, concentration of salts in the soil water can be held below damaging levels. This overcomes one of the problems of using saline water with conventional systems where the soil moisture fluctuates between field capacity and something above wilting point over 2 to 3 weeks. The method also avoids leaf burn which can occur due to overhead sprinkler irrigation with saline water.

However, proclaimed virtues of localized irrigation with saline water should be treated with caution because a build-up of toxic salts in the soil and ruin of soil structure by sodium salts can occur with localized irrigation just as they can with any other system.

(vi) Better use of poor soils

Very heavy soils with infiltration rates of 2 to 4 mm/h can be difficult to irrigate by sprinkler methods. Furthermore, very light soils cannot be successfully irrigated by surface methods. Localized systems have been successfully used on both kinds of soil.

(vii) Reduction of operating costs and utilization of lower discharges

In general, the total operating pressure of a localized system will be 50 to 70 percent of a conventional sprinkler system, thus operating costs may be reduced. In addition, the discharge within the system is generally low, which allows the utilization of low yielding water points such as springs and shallow wells.

1.5.2 Problems

(i) Sensitivity to clogging

The main problem with localized irrigation is the susceptibility of the small water passageways of the distributors to blockage. Causes of blockages include sand, silt, organic matter, algae, bacterial slimes, precipitation of nutriments or undissolved nutriments, colloidal or dissolved iron when present in conjunction with "iron bacteria", colloidal material and precipitation of calcium carbonate at high temperature. A recent survey has shown that causes of clogging may be rated as follows:

biological	37%
chemical	22%
physical	31%
uncertain	10%

Good filtration, using self-cleaning suction filters and sand/gravel filters can eliminate sand, silt and undissolved nutriments and can markedly reduce organic matter, algae and bacterial slimes. Protection against precipitation of chemicals, or the growth of iron bacteria, requires pre-treatment with chemicals. Where treatment as necessary is not possible for practical or economic reasons a localized method should not be used.

(ii) Salinity build-up

Localized irrigation, like any other method of irrigation, has its potential salinity problems, but much can be done by managing water and soils to prevent salinity damage.

Without remedial action zones of salt accumulation may occur, particularly at the outer edges of the wetted soil mass, and a light rain can move the salts downward into the root zone, sometimes causing severe damage to shallow-rooted crops. In some cases of low rainfall, supplementary sprinkler or surface irrigation may be necessary to leach the excess of salt.

(iii) Limited root development

With localized irrigation, roots will concentrate in the wetted zone. If this zone is too small, the spread of roots will be inadequate. Hence yields may be affected and trees might be blown over in strong winds. However, correct placement of drippers should overcome this danger.

Another disadvantage of a confined root system which has become accustomed to "regular feeds" is that, if the water supply should fail, the plant would suffer more from stress than one which had developed under a conventional irrigation system. Therefore, while the water supply for localized methods can be less abundant than for conventional methods, it must be absolutely reliable.

Although crops may grow in partially wetted soil, a minimum wetted areas appears to be required for optimum growth. The extent to which the soil profile is wetted is a function of the volume of water applied at each irrigation.

(iv) Atmospheric control

Permanently set sprinkler irrigation systems are often used for protecting fruit trees and vegetables from frost, for sunburn protection of ginger, or humidity control for vegetables or flowers. Localized irrigation does not provide this atmospheric control.

1.6 CONCLUSIONS

From experience gained so far in the application of localized irrigation in various parts of the world, the following conclusions may be drawn.

Localized irrigation should not be regarded as a universal panacea or substitute for long-established and proven methods such as basin, flood, furrow or sprinkler irrigation. It is just another way of irrigating, the advantages and disadvantages of which have to be considered in comparison with more conventional methods in each particular case.

Where localized irrigation can be used successfully, an important and far-reaching benefit is the saving of scarce water supplies and elimination of the need for expensive drainage works.

As far as crop yield is concerned, trials have shown increased yields and lower water consumption on desert sands using saline water compared to conventional methods under the same conditions. On the other hand, well managed surface or sprinkler systems using good quality water on clay loam soils have produced similar yields to localized systems under the same conditions and with only slightly higher water consumption. This leads to the conclusion that in areas suitable for conventional methods the advantages of a change to localized irrigation will appear in the form of ease of management, reduction in labour and easier control of pests and weeds, rather than in a significant increase in yield.

It follows that in certain cases saline water may be used more successfully with localized systems than with conventional methods, but great care must be exercised in the design and operation of the system. This attribute does, however, enhance interest in the possibilities of localized systems in areas of scarce and poor quality water supplies. Conversely, in areas of high rainfall occurring over short periods, localized systems may be used to provide supplementary irrigation during the intervening dry periods.

Localized irrigation is used most in cases where the cost of water is high, on sloping or undulating land, where labour is scarce and expensive, and where the water quality is marginal.

2. DESIGN PROCEDURE

2.1 CROP WATER REQUIREMENTS

As a first step in the proper design of an irrigation scheme it is necessary to know the crop water requirements. The data required can be obtained by measuring the amount of water used by different crops under field conditions. Direct measurement procedures are laborious and time-consuming. Consequently a large number of estimation methods have been developed. The four most widely known and used are the Blaney-Criddle, Radiation, Penman and Pan Evaporation methods.

2.1.1 Definition

In general terms, the crop water requirement is equivalent to the rate of evapotranspiration necessary to sustain optimum plant growth.

More specifically, the water requirement is defined herein as the rate of evapotranspiration of a disease-free crop growing in a field of not less than one hectare under optimal soil conditions. The optimal soil conditions assume adequate fertility and water to achieve the full production potential of the crop under the prevailing environment. The crop water requirement is designated as ET_{crop} and is expressed in millimetres per day (mm/day) or inches per day (in/day).

2.1.2 Determination of Crop Water Requirements

The accuracy of the determination of crop water requirements will be largely dependent on the type of climatic data avilable and the accuracy of the method chosen to estimate the evapotranspiration. The Penman and Radiation methods are best for mean estimates over short periods of about 10 days. The Pan Evaporation method is often the second choice, but can be superior with excellent siting and light winds. In many climates the Blaney-Criddle method is best for periods of one month or more.

Procedures for the calculation of crop water requirements are detailed in FAO Irrigation and Drainage Paper 24. In brief, these procedures are divided into four stages as follows:

(i) Calculation of reference crop evapotranspiration (ET_o)

The reference crop evapotranspiration value ET_o is defined as "the rate of evapotranspiration from an extended surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water".

Based on meteorological data available, a method to calculate ET_o is selected - Penman, Radiation, Pan or other if applicable.

ET_o is computed for each 30 or better 10-day period using mean climatic data.