WASTEWATER MANAGEMENT FOR IRRIGATION

Principles and Practices

Research Advances in Sustainable Micro Irrigation

VOLUME 8

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Principles and Practices

Edited by

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LIST OF ABBREVIATIONS

ASABE	American Society of Agricultural and Biological Engineers
CU	coefficient of uniformity
DIS	drip irrigation system
DOY	day of the year
EPAN	pan evaporation
ET	evapotranspiration
ETc	crop evapotranspiration
FAO	Food and Agricultural Organization, Rome
FC	field capacity
FUE	fertilizers use efficiency
gpm	gallons per minute
ISAE	Indian Society of Agricultural Engineers
kc	crop coefficient
kg	kilograms
Kp	pan coefficient
lps	liters per second
lph	liter per hour
msl	mean sea level
PE	polyethylene
PET	potential evapotranspiration
pH	acidity/alkalinity measurement scale
PM	Penman-Monteith
ppm	one part per million
psi	pounds per square inch
PVC	poly vinyl chloride
PWP	permanent wilting point
RA	extraterrestrial radiation
RH	relative humidity
RMAX	maximum relative humidity
RMIN	minimum relative humidity

RMSE	root mean squared error
RS	solar radiation
SAR	sodium absorption rate
SDI	subsurface drip irrigation
SW	saline water
SWB	soil water balance
TE	transpiration efficiency
TEW	total evaporable water
TMAX	maximum temperature
TMIN	minimum temperature
TR	temperature range
TSS	total soluble solids
TUE	transpiration use efficiency
USDA	US Department of Agriculture
USDA-SCS	US Department of Agriculture-Soil Conservation Service
WSEE	weighed standard error of estimate
WUE	water use efficiency

LIST OF SYMBOLS

A	cross sectional flow area (L^2)
AW	available water
Cp	specific heat capacity of air, in J/(g·°C)
CV	coefficient of variation
D	accumulative intake rate (mm/min)
d	depth of effective root zone
D	depth of irrigation water in mm
Δ	slope of the vapor pressure curve (kPa°C^{-1})
e	vapor pressure, in kPa
e_a	actual vapor pressure (kPa)
E	evapotranspiration rate, in g/(m^2·s)
Ecp	cumulative class A pan evaporation for two consecutive days (mm)
eff	irrigation system efficiency
E_i	irrigation efficiency of drip system
E_p	pan evaporation as measured by Class-A pan evaporimeter (mm/day)
E_s	saturation vapor pressure, in kPa
E_{pan}	class A pan evaporation
ER	cumulative effective rainfall for corresponding two days (mm)
e_s	saturation vapor pressure (kPa)
$e_s – e_a$	vapor pressure deficit (kPa)
ET	evapotranspiration rate, in mm/year
ETa	reference ET, in the same water evaporation units as Ra
ETc	crop-evapotranspiration (mm/day)
ET_o	the reference evapotranspiration obtained using the Penman-Monteith method, (mm/day)
ET_{pan}	the pan evaporation-derived evapotranspiration
EU	emission uniformity

F	flow rate of the system (GPM)
F.C.	field capacity (v/v, %)
G	soil heat flux at land surface, in W/m^2
H	plant canopy height in meter
h	soil water pressure head (L)
I	infiltration rate at time t (mm/min)
IR	injection rate, GPH
IRR	irrigation
K	unsaturated hydraulic conductivity (LT^{-1})
K_c	crop-coefficient for bearing 'Kinnow' plant
Kp	pan factor
K_p	pan coefficient
n	number of emitters
P	percentage of chlorine in the solution*
Pa	atmospheric pressure, in Pa
P.W.P.	permanent wilting point
Q	flow rate in gallons per minute
q	mean emitter discharges of each lateral (lh^{-1})
R	rainfall
r_a	aerodynamic resistance (s m^{-1})
R_a	extraterrestrial radiation, in the same water evaporation units as ETa
R_e	effective rainfall depth (mm)
R_i	individual rain gauge reading in mm
R_n	net radiation at the crop surface (MJ $m^{-2}day^{-1}$)
R_s	incoming solar radiation on land surface, in the same water evaporation units as ETa
RO	surface runoff
r_s	bulk surface resistance (s m^{-1})
S	sink term accounting for root water uptake (T^{-1})
Se	effective saturation
S_p	plant-to-plant spacing (m)
S_r	row-to-row spacing (m)
SU	statistical uniformity (%)
S_ψ	water stress integral (MPa day)
t	the time that water is on the surface of the soil (min)

T	time in hours
V	volume of water required
V_{id}	irrigation volume applied in each irrigation (liter $tree^{-1}$)
V_{pc}	plant canopy volume (m^3)
W	canopy width
W_p	fractional wetted area
z	vertical coordinate positive downwards (L)

Greek Symbols

α	inverse of a characteristic pore radius (L^{-1})
γ	psychrometric constant (kPa°C^{-1})
θ	volumetric soil water content (L^3L^{-3})
θ(h)	soil water retention (L^3L^{-3}),
θ_r	residual water content (L^3L^{-3})
θ_s	saturated water content (L^3L^{-3})
θ_{vol}	volumetric moisture content (cm^3/cm^3)
λ	latent heat of vaporization (MJ kg^{-1})
λ*E*	latent heat flux, in W/mo
ρa	mean air density at constant pressure (kg m^{-3})

PREFACE

Due to increased agricultural production, irrigated land has increased in the arid and sub-humid zones around the world. Agriculture has started to compete for water use with industries, municipalities and other sectors. This increasing demand along with increments in water and energy costs have made it necessary to develop new technologies for the adequate management of water. The intelligent use of water for crops requires understanding of evapotranspiration processes and use of efficient irrigation methods.

Every day, news on water scarcity appears throughout the world, indicating that government agencies at central/state/local levels, research and educational institutions, industry, sellers and others are aware of the urgent need to adopt micro irrigation technology that can have an irrigation efficiency up to 90%, compared to 30–40% for the conventional gravity irrigation systems. I stress the urgent need to implement micro irrigation systems in water scarcity regions.

Irrigation has been a central feature of agriculture since the start of civilization and the basis of the economy and society of numerous societies throughout the world. Among all irrigation systems, micro irrigation has the highest irrigation efficiency and is most efficient. Micro irrigation is sustainable and is one of the best management practices. The water crisis is getting worse throughout the world, including in the Middle East and Puerto Rico where I live. We can, therefore, conclude that the problem of water scarcity is rampant globally, creating the urgent need for water conservation. The use of micro irrigation systems is expected to result in water savings, and increased crop yields in terms of volume and quality. The other important benefits of using micro irrigation systems include expansion in the area under irrigation, water conservation, optimum use of fertilizers and chemicals through water, and decreased labor costs, among others. The worldwide population is increasing at a rapid rate, and it is imperative that food supply keeps pace with this increasing population.

Micro irrigation, also known as trickle irrigation or drip irrigation or localized irrigation or high frequency or pressurized irrigation, is an irrigation method that saves water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant. It supplies controlled delivery of water directly to individual plants and can be installed on the soil surface or subsurface. Micro irrigation systems are often used for farms and large gardens but are equally effective in the home garden or even for houseplants or lawns.

Water and fertigation management are important practices for the success of drip/micro/trickle irrigation. Water management is the activity of planning, developing, distributing and optimum use of water resources under defined water policies and regulations. It includes: management of water treatment of drinking water/industrial water; sewage or wastewater; management of water resources in agriculture; management of flood protection; management of irrigation; management of the water table; and management of drainage, etc.

Reuse of wastewater in irrigation is being practiced only recently to solve water scarcity problems in agriculture. Management of water, soil, crop and operational procedures, including precautions to protect farm workers, play an important role in the successful use of sewage effluent for irrigation. Appropriate water management practices must be followed to prevent salinization, irrespective of whether the salt content in the wastewater is high or low. If salt is not flushed out of the root zone by leaching and removed from the soil by effective drainage, salinity problems can build up rapidly. Leaching and drainage are thus two important water management practices to avoid salinization of soils. One of the options that may be available to farmers is the blending of treated sewage with conventional sources of water, canal water or ground water, if multiple sources are available. It is possible that a farmer may have saline ground water and, if he has non-saline treated wastewater, can blend the two sources to obtain a blended water of acceptable salinity level. Further, by blending, the microbial quality of the resulting mixture can be superior to that of the unblended wastewater. Another strategy is to use the treated wastewater alternately with the canal water or groundwater, instead of blending.

From the point of view of salinity control, alternate applications of the two sources will be superior to blending.

Our goal is to improve permanently existing land and soil conditions in order to make irrigation with wastewater easier. Typical activities include leveling of land to a given grade, establishing adequate drainage (both open and sub-surface systems), deep ploughing and leaching to reduce soil salinity.

The procedures involved in preparing plans for effluent irrigation schemes are similar to those used in most forms of resource planning and summarized the main physical, social and economic dimensions (Appendix K in this book).

Adopting a mix of effluent use strategies is normally advantageous in respect of allowing greater flexibility, increased financial security and more efficient use of the wastewater throughout the year, whereas a single-use strategy will give rise to seasonal surpluses of effluent for unproductive disposal. Therefore, in site and crop selection, the desirability of providing areas for different crops and forestry so as to utilize the effluent at maximum efficiency over the whole yearly cycle of seasons must be kept in mind.

Among the soil properties important from the point of view of wastewater application in irrigation are: physical parameters (such as texture, grading, liquid and plastic limits, etc.), permeability, water-holding capacity, pH, salinity and chemical composition. After elimination of marginal sites, each site under serious consideration must be investigated by on-site borings to ascertain the soil profile, soil characteristics and location of the water table. When a site is developed, a long-term groundwater-monitoring program should be an essential feature of its management.

The degree to which the use of treated effluent influences crop selection will depend on government policy on effluent irrigation, the goals of the user and the effluent quality. Government policy will have the objectives of minimizing the health risk and influencing the type of productivity associated with effluent irrigation. Regulations must be realistic and achievable in the context of national and local environmental conditions and traditions. At the same time, planners of effluent irrigation schemes must attempt to achieve maximum productivity and water conservation through the choice of crops and effluent application systems.

A multiple-use strategy approach will require the evaluation of viable combinations of the cropping options possible on the land available. This will entail a considerable amount of survey and resource budgeting work, in addition to the necessary soil and water quality assessments. The annual, monthly and daily water demands of the crops, using the most appropriate irrigation techniques, have to be determined. Domestic consumption, local production and imports of the various crops must be assessed so that the economic potential of effluent irrigation of the various crop combinations can be estimated. Finally, the crop irrigation demands must be matched with the available effluent so as to achieve optimum physical and financial utilization throughout the year.

The mission of this compendium is to serve as a reference manual for graduate and undergraduate students of agricultural, biological and civil engineering; horticulture, soil science, crop science and agronomy. I hope that it will be a valuable reference for professionals who work with micro irrigation/wastewater and water management and for professional training institutes, technical agricultural centers, irrigation centers, agricultural extension services, and other agencies that work with micro irrigation programs.

After my first textbook, *Drip/Trickle or Micro Irrigation Management* published by Apple Academic Press Inc., and response from international readers, I was motivated to bring out for the world community this 10-volume series on Research Advances in Sustainable Micro Irrigation. This book series will complement other books on micro irrigation that are currently available on the market, and my intention is not to replace any one of these. This book series is unique because of its worldwide applicability to irrigation management in agriculture. This series is a must for those interested in irrigation planning and management, namely, researchers, scientists, educators and students.

The contribution by the authors to this book series has been most valuable in the compilation of these volumes. Their names are mentioned in each chapter and in the list of contributors of each volume. This book would not have been written without the valuable cooperation of these investigators, many of whom are renowned scientists who have worked in the field of micro irrigation throughout their professional careers. I am glad to introduce Dr. Vinod Kumar Tripathi, Assistant Professor and