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Optimizing drip Irrigation system design for Onion crop using DIDAS software

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ABSTRACT

Water is a key limiting factor in crop production. Use of drip irrigation system for growing vegetable crops can help in sustainable use of water. In close growing crops like onion which has shallow root zone depth (i.e. 8inches) designing drip irrigation system which will cover the crop water requirements effectively becomes important. DIDAS software is used in design of drip irrigation systems and irrigation scheduling of various annual crops and trees at various soils and evaporation conditions. DIDAS's drip system design tool can be used for optimizing design of drip irrigation system which is based on steady irrigation and water uptake processes to study the effect of geometrical attributes on water use efficiency. Geometrical attributes includes distances between emitters along driplines and between driplines, the depth of emitters for subsurface systems and the size, and depth of root zone in systems. It performs computations based on analytical solutions of the relevant linearized water flow and uptake problems. Design tool is based water uptake rate criterion (RWUR, ratio between water uptake rate and irrigation rate) assuming no plant-atmosphere resistance to water uptake based on three input parameters describing the soil texture, the size of the root zone and the potential evaporation. The design tool compute the RWUR and its output is the RWUR as a function of the radius of the root zone(r_0) for different emitter or dripline spacing, depending on the chosen scenario. The program was run for different emitter spacing, it evaluated relative water uptake rate (RWUR) as a function of root zone radius (r_0), and best emitter spacing was selected based on results.

Keywords: *Irrigation management, Trickle irrigation, Water use efficiency, Drip irrigation*

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INTRODUCTION

Water is a main resource for sustaining human population Food production is the major user of water worldwide water is used for providing supplemental irrigation to the growing crops. Water plays a vital role in food production help in achieving food security for the nation to take care of the increasing population by enhancing its current irrigation potential and make judicious use of available supply of water or else the country will become water stressed in the coming years. Therefore developing and using latest technologies for water harvesting and storage, technologies for precision water application is needed. Drip-irrigation is the most efficient irrigation method known with 90-95 % efficiency and more water saving when compared to other methods of irrigation [1], there is little to no water loss due to evaporation or runoff. Proper designing of drip irrigation system plays vital role in its proper and efficient functioning, design of drip irrigation system depends on several factors like land, soil, crop, climate etc. Drip irrigation can be used for different types of crops but designing drip irrigation system depending on needs of specific crop can be major problem. Finding optimum spacing between emitters along dripline for different crop to obtain uniform application of water and proper moisture in root zone of the crop can be difficult and time consuming process if done by means of field trails and experiments. Simulation and modeling provides an efficient alternative to this problem.

There are different computer programs available which are based on analytical or numerical solutions that can simulate water uptake, water dynamics in the soil and wetting patterns in root zones in surface and subsurface irrigation systems eg: WetUp [2] which based on analytical solutions and HYDRUS 2D/3D

[13], So-WaM [14], Neuro-Drip [10], CoupModel [10] and Drip-Irriwater [1] are based on numerical solutions. Models take into account the soil and the root system properties, the climate, and the plant/emitter configuration of the irrigation system and simulate soil water status in the active root zone. DIDAS [12] is similar computer software which is based on analytical solutions of the Richards equation for steady and unsteady water flow in point and line source emitters/sources from surface and subsurface in semi-infinite soil domain. DIDAS can be used for assessing existing system designs and irrigation schedules and for developing new, water-use-efficient designs and schedules. This software can be especially useful finding optimal emitter spacing for close growing crop like onion which needs closely spaced drip lines without costly and time consuming field trails and experiments. In this study we used DIDAS software for optimizing emitter spacing for Onion crop by running simulation for different lateral spacing and compare results by comparing relative water-uptake rate (RWUR, ratio between water uptake rate and irrigation rate) for different spacing at different depth to determine optimal lateral spacing for Onion crop.

Description of Model

DIDAS [9] is a freeware developed in Israel which is based on analytical solutions of the Richards equation for steady and unsteady water flow from point and line sources present at surface or subsurface in semi-infinite soil domain. Solutions are based on relationships between the parameters of the flow equation, the source type, the geometry of the domain, and the initial and boundary conditions. This software consists of three modules first is drip-system design module which uses data about root-zone, plant resistance, the configuration of the water source and its location, and soil hydraulic parameters to simulate water uptake processes and determine effect of geometric attributes on water use efficiency. Second is diurnal pattern module which simulate diurnal patterns of plant-atmosphere resistance to water uptake and evaporation, it is primary step for evaluating irrigation scheduling. Third moduleis irrigation-scheduling optimization tool which used to simulate effect of different irrigation schedules but doesn't calculate direct effect of irrigation schedules in terms of yield but calculate RWUE(Relative Water use efficiency) for optimizing irrigation scheduling. For our study we are mainly concerned with drip-system design module.

MATERIAL AND METHODS

In this study we used DIDAS software to simulate relative water uptake rate (RWUR) for a drip irrigation system in onion crop. Onion (*Alium cepa* L.) is close growing crop grown generally at a spacing of 15 cm (row to row) and 10 cm (plant to plant). Crop root zone is up to 20 cm depth below soil surface. We used DIDAS's drip system design module to run simulation for Onion crop grown in Sandy loam soil irrigated by surface drip irrigation system with different lateral spacing starting from 15 cm increasing it by 15 cm in each run upto 75 cm and determined relative water uptake rate (RWUR) as function of root radius (r_0).

Drip system design module

This module is based on analytical solutions to irrigation and water uptake processes under steady state flow condition. It is used to aid in making decisions regarding emitters spacing along driplines, spacing between the laterals, depth for subsurface systems. It is based on coupled source-sink model for evaluating the relative water uptake rate (RWUR) which is water uptake rate relative to the water supply rate to be used as a design criterion.

Plant water uptake rate depends on the size of root-zone, plant resistance, water source configuration and its location, and soil hydraulic properties. DIDAS can be used for assessing existing design or to design a new system altogether based on the given input parameters. Main input parameters that are required to run the simulation are Soil Parameters, Evaporation, Plant Resistance, Vertical configuration and horizontal configuration of the system.

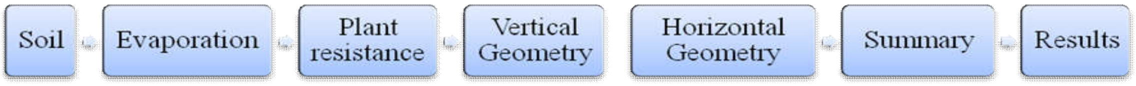

Figure 1: Flow chart of various steps involved in simulating a scenario in Drip system design module

Soil Parameters

The soil-type parameters (α, k_{eff}, β, K_s, h_s, n)are required to be inputted by user or selected from resource library based on type of soil from the existing catalogue. The values of α (cm^{-1}) and K_s ($cm\ h^{-1}$) can be assigned by user or find out using the relation: $\alpha = 0.04035\ K_s^{1/2}$ [4].

DIDAS uses the Gardner–Philip exponential hydraulic conductivity function, $K(h)$:

$$K = K_s \exp[\alpha(h + \beta z)]$$

Where,
h is the matric head (cm)
"α" – Soil texture coefficient (cm^{-1})
"K_s" – Hydraulic conductivity at water saturation (cm h^{-1})
"β" – A parameter describing the downward increase (when $\beta>0$) or decrease (when $0>\beta>-1$)

Evaporation

DIDAS also accounts for evaporation from the surface of soil, which is greatest near the emitters (driplines) and decreases to zero when taken at greater distance from the water sources. Vertical water flux component at the soil surface (Lomen and Warrick) is given by

$$v_{ev} = -(\alpha/2) m \varphi$$

Where*m* is a positive ($m \geq 0$) constant associated to the atmospheric evaporation demand.

Plant Resistance

Local plant-atmosphere resistance (ζ)to water uptake a dimensionless quantity is accounted for by DIDAS. It is determined by local soil-plant-atmosphere processes acting against the resistance of the soil to conduct water from the emitters (sources) to the root systems (sinks). Generally we Assign ζ a value of 0 which means that there no plant-atmosphere resistance, which is recommended for design module.

Vertical Configuration

In we select the location of drip which can either on-surface or sub-surface having root zone above or below emitter. Then we define the location and size of the root zone, we input emitter depth (z_{so}) and root zone depth (d_0). We input depth of emitters zero as we have drip system on surface which is represented by black dot on surface and root zones represented by green circle.

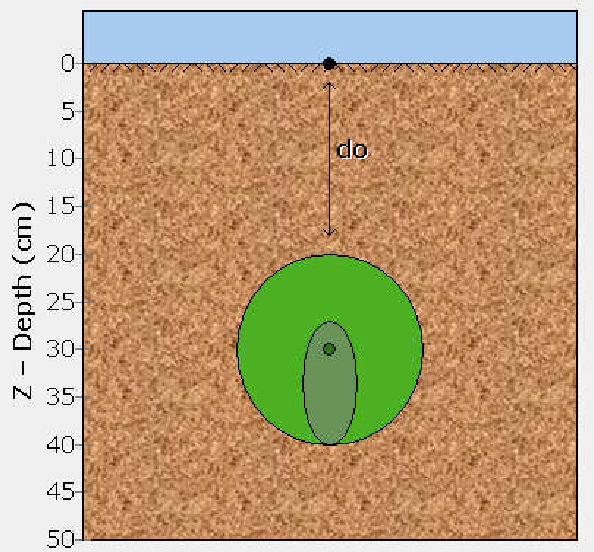

Figure 2: Vertical soil cross-section for given scenario in DIDAS window of the design module.

Horizontal Configuration

Then we select point source emitters represented by black dots and the corresponding root zones by green circles which are spherical and the flow problem is three-dimensional then we define geometry of the drip-irrigated field. We selected rectangular array of emitters/plants option which selects a setup with parallel, equally-spaced driplines and plant rows with equally-spaced, coupled emitter. User inputs the dripline spacing (x_{so}) which is the fixed spacing between driplines, min emitter spacing (y_{so}) which is the minimum emitter) spacing along the driplines (cm) and inc emitter spacing (y_{so}) the desired increment between the spacing of the emitters to be increased in each run of simulation.

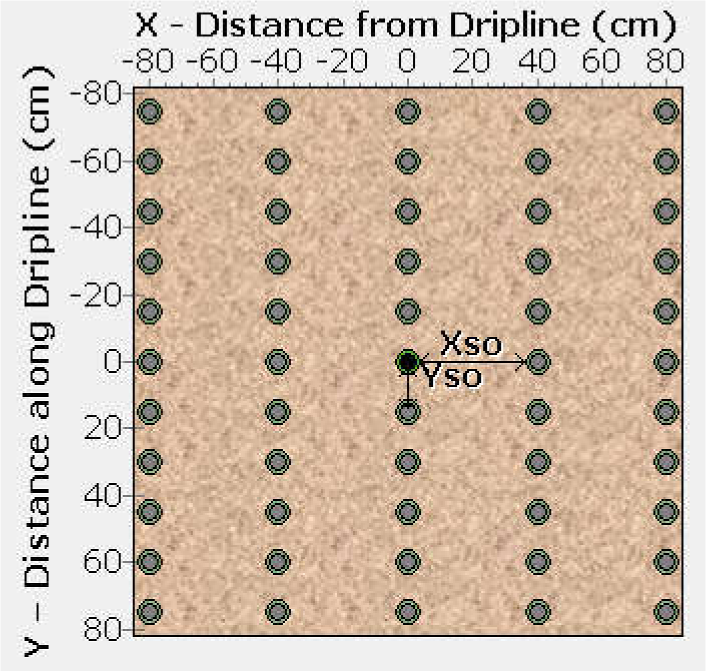

Figure 3: Figure Horizontal configuration for given scenario in DIDAS window of the design module.

DIDAS Scenario: Drip System Design
Soil:
Name: Loamy Sand (New)
α: 0.128 1/cm
K_s: 10 cm/h
k_{eff}: 25.22 cm/h
n: 2.8
θ_s: 0.4
β: 0
Evaporation:
None
Plant-Atmosphere Resistance:
None
Geometry:
On-Surface Irrigation
Root Zone Depth (d_0): 20 cm
Point Sources/Sinks
Rectangular Array of Emitters/Plants
Emitter Spacing (y_{so}): 15 + Δ15 cm
Dripline Spacing (x_{so}): 40 cm

RESULTS AND DISCUSSION

The output of the program after computing for different scenarios display the relative water uptake rate (RWUR) as a function root zone radius (r_0) from 0 to a maximum value constrained by the horizontal and vertical configuration of the system. For each emitter spacing starting from 15 cm to 75 cm increasing by 15cm for each run and the root zone radius (r_0) varies from 0.5 cm to half the spacing between two adjacent emitters. In general, for greater spacing between emitters and drip line, the RWUR goes through a local minimum and then increases with increasing r_0. RWUR will always decrease with increasing distances between emitters and between drip lines. For deeper root zones (i.e., $d_0 > 0$) RWUR would increase monotonically with increasing r_0 for all emitter spacing [3-7]. The RWURs computed by DIDAS are found to be 70–90% which higher than those usually measured generally in field experiments which is around 60% [1, 2], This is due to reason that DIDAS design module performs calculations for steady state flow of water and uptake. For our simulation in DIDAS design module result were presented in the term of RWUR (qsi/qso) as a function of the radius of root zone (r_0) for five emitter spacing of 15–75 cm under assumption there is no evaporation from soil surface (i.e., m = 0) and there is no plant resistance (ζ= 0). Results were obtained in terms of a graph between RWUR (qsi/qso) vs. the radius of root zone (r_0) and a same data in table form was obtained which was latter analyzed using relevant statistical tool for significance. Mean RWUR have been found highest for 30 cm spacing. Value of adjusted R square was highest and standard error was lowest for 60 cm emitter spacing. Results data analysis on simulated results are given in Table 1 and Table 2.

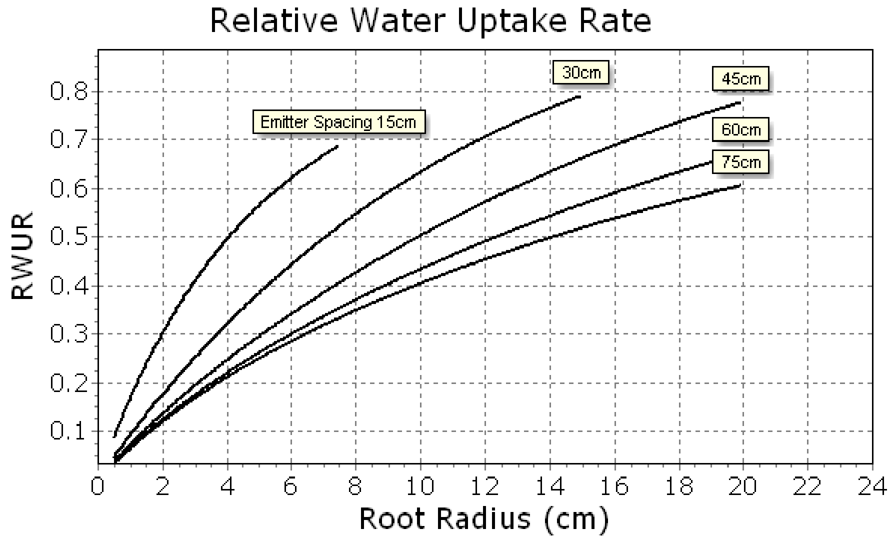

Figure 4: DIDAS design module output window, presenting the RWUR (qsi/qso) as a function of the radius of the conceived root zone (r0) for five emitter spacing(15-75 cm).

Table 1: Descriptive Statistics Simulation results.

Descriptive and Regression Statistics:

	RWUR (Emitter Spacing 15 cm)	RWUR (Emitter Spacing 30 cm)	RWUR (Emitter Spacing 45 cm)	RWUR (Emitter Spacing 60 cm)	RWUR (Emitter Spacing 75 cm)
Valid	180	372	500	500	500
Missing	320	128	0	0	0
Mean	0.4600	0.4969	0.4794	0.4148	0.3835
Std. Error of Mean	0.01274	0.01103	0.009381	0.007942	0.007073
Median	0.4954	0.5350	0.5118	0.4410	0.4107
Std. Deviation	0.1709	0.2127	0.2098	0.1776	0.1581
Variance	0.02920	0.04524	0.04400	0.03154	0.02501
Minimum	0.08841	0.04791	0.03773	0.03478	0.03388
Maximum	0.6880	0.7894	0.7769	0.6717	0.6059

Table 2: Regression Statistics Simulation results

Regression Statistics	**RWUR (Emitter Spacing 15 cm)**	**RWUR (Emitter Spacing 30 cm)**	**RWUR (Emitter Spacing 45 cm)**	**RWUR (Emitter Spacing 60 cm)**	**RWUR (Emitter Spacing 75 cm)**
Multiple R	0.981730065	0.986603817	0.989355606	0.98952128	0.98564
R Square	0.96379392	0.973387091	0.978824515	0.979152364	0.971486
Adjusted R Square	0.963590515	0.973315164	0.978781994	0.979110501	0.971429
Standard Error	0.032603459	0.034746542	0.030555188	0.025668341	0.026732

CONCLUSIONS

DIDAS software can be used as a good decisions support system tool for designing drip irrigation systems and irrigation scheduling by simulating water flow and uptake in the soil, different design parameters like distances between emitters and between drip lines, the depth and location of subsurface emitter can easily be found by simulating different scenarios in computer simulation than in the actual field and simulated results can be verified using field experiments. DIDAS requires very few and easily available soil, plant, and climatic input parameters to operate successfully and is very user-friendly.

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