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Research Article

DIMSUB, a computer program for designing microirrigation subunits. Tool definition and case studies

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ABSTRACT: DIMSUB is a computer program to complement a decision support tool (DST) to effectively study different hydraulic design alternatives in microirrigation systems. We developed environments in Visual Basic for applications for Microsoft Excel® that allow specific step-by-step functions to be created for the design of irrigation subunits. Different alternatives can be considered, such as types of emitter, lateral and submain pipe sizes, different feeding points, irregular subunit shapes and topography slopes. Furthermore, specific uniformity criteria need to be considered to achieve efficient water applications and proper design systems. Lengths of run lateral and submain pipes, position of the hydrant connection, pressure head and head loss in pipes or pressure-compensating emitters can be assigned to evaluate the results and choose the best design alternative. This user-friendly tool to study hydraulic variables is expected to be a valuable aid for the decision-making process in designing irrigation systems. Some examples of practical cases under specific crop conditions to design drip irrigation subunits are given using DIMSUB.

Keywords: irrigation, emission uniformity, dripper, manifold

Introduction

Modernization of irrigation systems in the Mediterranean Basin is necessary in rural areas, due to water scarcity. Changing to pressure irrigation systems, in which water can be effectively controlled and supplied, requires systems to be appropriately designed and managed.

In microirrigation, a subunit is the set of lateral pipes connected to a manifold and controlled by a manual or automatic pressure-regulating valve (Figure 1). The correct design of this system is essential to distribute water and fertilizers uniformly in the field (Wu and Barragan, 2000, Holzapfel et al., 2009, Carrión et al., 2014). Attempts have been made by several researchers to design the hydraulics of subunits. Myers and Bucks (1972), Howell and Hiler (1974), Wu and Gitlin (1975, 1983) studied the behavior of flow conditions along lateral pipes and the manifold. Wu (1997) studied the analysis of single diameter laterals based on the energy line analytical approach. Bralts and Segerlind (1985) and Bralts et al. (1993) used the finite element numerical approach to analyze microirrigation systems. Pitts et al. (1986) used the step-by-step numerical method for the trickle irrigation design. Hoffman et al. (2007) widely reviewed the design of microirrigation systems. Recently, researchers have worked on this issue to improve the design using computer-aided design techniques. Ravindra et al. (2008) presented a linear programming model for optimal design of pressurized irrigation subunits. Carrión et al. (2013) developed Presud to identify the optimum microirrigation subunit design using the total annual water application cost per unit area (investment, maintenance, energy and water consumption). Pedras et al. (2009) proposed a complex multicriteria decision support tool (DST) to generate different design scenarios.

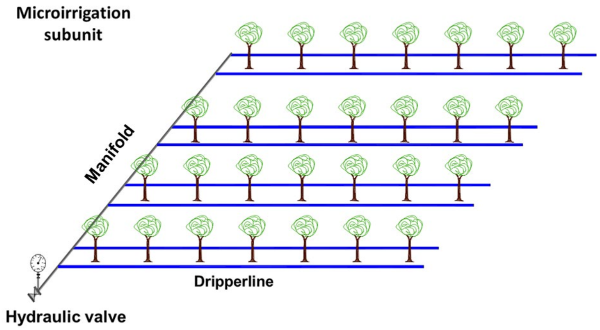


Figure 1 – Components of a microirrigation subunit.

The main objective of the subunit design is therefore to reach maximum application efficiency by satisfying the plant needs, for which highly uniform water distribution is required.

This paper describes a decision support tool, DIMSUB, aimed to design irrigation subunits. Case studies are evaluated with this computer application entering all the necessary variables required for the design of irrigation subunits in different terrains. Main hydraulic parameters to achieve uniform irrigation are obtained and designers can decide the best solution in terms of water distribution, pressure head requirements and material cost.

Materials and Methods

The design of irrigation subunits involves the correct selection and size of all components in the system, especially the type of emitter, lateral and manifold pipes, ensuring their technical characteristics.

Field uniformity is affected by a combination of a number of design variables that influence pressure and flow rate at the emitter as well as the pressure variation permitted in the system (Wu, 1997; Pereira et al., 2002). Even quality of emitters, expressed with the manufacturer's coefficient of variation (CV), affects the uniformity of field emission (Carrion et al., 2013; Zhang et al., 2013).

The relationship between the emitter flow rate and pressure head is established by emitter hydraulic characteristic:

$$q = k_e \,.\, H^x \tag{1}$$

where: q = emitter flow rate (L h^{-1}); H = pressure head (m); k_e = emitter discharge coefficient; x = exponent of discharge, close to 0 for pressure-compensating (PC) emitters and 0.5 for non-pressure-compensating (NPC) emitters.

Variation in the emitter flow rate of an irrigation subunit is defined by the expression:

$$q_{var} = (q_{max} - q_{min}) \cdot \overline{q}^{-1} \tag{2}$$

where: q_{max} = maximum emitter flow rate (L h^{-1}); q_{min} = minimum emitter flow rate (L h^{-1}); $\overline{q}$ = average flow rate in the subunit (L h^{-1}).

The hydraulic principles involved in designing subunits are based on the fundamental conservation of energy and continuity equation. Pressure evolution in manifolds and laterals is mainly due to the slope and head losses in pipelines.

The total energy in a pipe, H, between sections 1 and 2 per unit weight of water (m), can be expressed by the steady flow energy equation:

$$H_1 = H_2 + h_{tot}$$

$$\left(z + \frac{P}{\gamma} + \frac{\upsilon^2}{2g}\right) = \left(z + \frac{P}{\gamma} + \frac{\upsilon^2}{2g}\right)_2 + h_{total} \tag{3}$$

where: z = elevation as potential energy (m); $\frac{P}{\gamma}$ = pressure head (m); $\frac{\upsilon^2}{2g}$ = velocity head (m) and h_{total} = friction and local or minor head losses (m).

Friction head losses can be estimated by the Darcy-Weisbach equation, in which the modified Blasius equation (1913) can be assumed to estimate the friction factor f for practically turbulent flow in smooth pipes:

$$f = 0.302 \cdot \mathrm{Re}^{-0.25} \tag{4}$$

where: f = friction factor and Re = Reynolds number within the range $3{,}000 < \mathrm{Re} < 10^5$ (Von Bernuth, 1990; Bagarello et al., 1995; Provenzano et al., 2005).

For the specific case in which head losses are estimated for a discrete flow distribution throughout a multioutlet lateral or manifold, a reduction coefficient F or Christiansen (1942) factor is introduced into head losses by the formula:

$$h_{total} = C \cdot K_m \cdot F \cdot L \cdot Q^{1.75} D^{-4.75} \tag{5}$$

where: C = head loss coefficient varying with water temperature, which is assumed ranging from 0.516 to 0.381 for 5 °C < T < 60 °C (Montalvo, 2007); D = inside diameter (mm); K_m = increasing coefficient accounting for minor head losses; F = Christiansen reduction factor (Christiansen, 1942); L = lateral or manifold length; Q = initial flow rate.

In this sense, the insertion of each emitter to the lateral and the connection to manifold introduce some additional losses that should be considered. Several researchers carried out different approaches to estimate this local loss in microirrigation laterals and proposed a constant equivalent length (l_e) for emitter connection to estimate local loss. In the last decade, researchers proposed new approaches to determine local losses (Provenzano et al., 2007, 2014; Wang et al., 2016; Ding et al., 2016). DIMSUB allows establishing the value of l_e and calculating an increasing coefficient to estimate local losses:

$$K_m = (s + l_e) \cdot s^{-1} \tag{6}$$

where: s = emitter spacing; l_e = equivalent length due to local head losses.

Consequently, iterative calculation methods help to determine the minimum pressure point along the lateral length and solve the energy gradient line produced in a lateral or manifold (Arviza and Palau, 2016). Design and sizing of subunits are based on emitter uniformity criteria by means of controlling their allowable pressure head variation.

Correct and precise design requires complex calculation procedures (Dandy and Hassanli, 1996; Lamm et al., 2007; Ravindra et al., 2008). Given the complexity of the design of the microirrigation subunit, in many cases sizing has been over-simplified to the detriment of precision and oversizing subunits. In many cases, even nowadays, many engineers use tables supplied by manufacturers to determine the maximum lateral lengths and neglect calculating the size of the manifold or the required initial pressure of the subunit.

DIMSUB was developed to provide freeware to engineers and technicians to design and size irrigation subunits appropriately and rapidly.

Microirrigation optimum design using DIMSUB

DIMSUB is a decision tool for designing microirrigation subunits on Microsoft Excel® by developing a series of user forms on Visual Basic for Applications.

Optimum design and sizing procedures start with specifying the possible maximum pressure head variation, ΔH_{sub}, in the irrigation system to ensure adequate uniformity (Valiantzas, 2003; Yildirim, 2008). The slope, terrain geometry, emitter type (nominal flow rate and hydraulic characteristic curve), lateral diameter and emitter spacing allow the analysis of the optimal micro-irrigation system design.

It can also be used to estimate the initial pressure and flow rate of a subunit to keep the energy requirements as low as possible. Figure 2 shows DIMSUB synthesized by the step-by-step method for the hydraulic design of subunits.

Maximum pressure head variation in the subunit for the non-pressure-compensating emitter, $\Delta H_{subunit}$, can be estimated by x, discharge exponent in the emitter hydraulic characteristic, and $\overline{h}$ or operating pressure head (m). Maximum pressure head variation can be shared among total head losses Δh_{sub} in the subunit, considering lateral and manifold and differences in elevation Δz_{sub} of lateral and manifold (m). DIMSUB allows establishing this value in PC emitters.

The size of the manifold pipe depends on the remaining maximum head loss after designing the laterals, as shown in the following equations (Keller and Bliesner, 1990):

$$\Delta H_{subunit} = \Delta H_{lat} + \Delta H_{manifold} = h_{lateral} + \Delta Z_{lat} + h_{manifold} + \Delta Z_{manifold} \quad (7)$$

$$h_{max\ manifold} = \Delta H_{subunit} - \Delta H_{lateral} - \Delta Z_{manifold} \quad (8)$$

where: $\Delta H =$ maximum pressure head variation in the subunit, lateral or manifold, respectively (m); $h_{max\ manifold}$ = maximum pressure head loss in manifold (m); ΔZ = elevation difference (m).

At this point, introducing all data related to the subunit, DIMSUB is able to calculate the remaining maximum head loss for the manifold (eq. 8) after designing the laterals and the minimum inside diameter (D_{min}) to keep the pressure head variation considered.

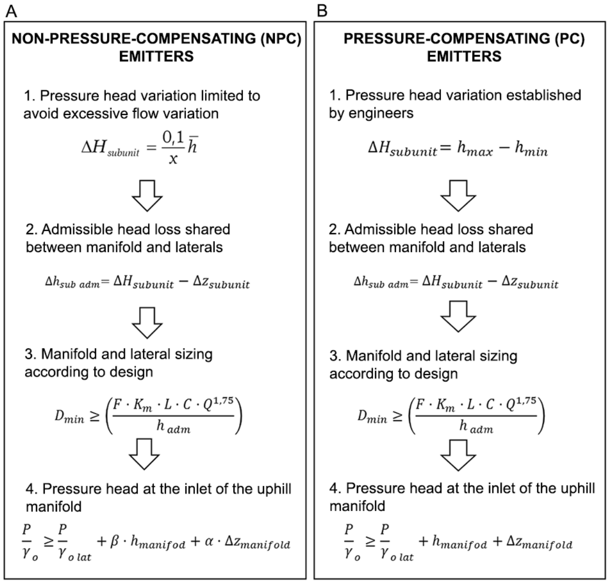


Figure 2 – Step-by-step method for irrigation subunits design using NPC emitters (A) and PC emitters (B). F is the Christiansen's reduction factor; L is the length of manifold (m); Q is the initial flow rate (L h^{-1}); Km is the increasing coefficient for local losses; h_{adm} are admissible head losses in manifold; α and β are adjustment coefficients to obtain average inlet pressure.

Additionally, this tool allows estimating the pressure head required at the subunit entrance, P/γ, considering head losses and subunit slopes to ensure flow uniformity. Keller and Karmeli (1975), in a study to achieve a better flow distribution, introduced α and β coefficients to adjust initial pressure head in multiple outlet pipes for non-pressure-compensating emitters. Keller and Bliesner (1990) proposed the formula to obtain the average head along the pipe. Montalvo (2007) justified adequate values for α and β, correcting difference in elevation and head losses along laterals and manifold. Values for each type of pipe configuration are calculated by DIMSUB considering that pressure-compensating emitters do not require this adjustment (Figure 2).

DIMSUB computer application estimates the emission uniformity coefficient (EU) in the microirrigation system with the following expression proposed by Keller and Karmeli (1975), and used later by ASAE (2005) with designing purposes:

$$EU = 100\left[1 - \left(1.27 \cdot \frac{CV}{\sqrt{n}}\right) \cdot \left(\frac{Q_{min}}{\overline{Q}}\right)\right] \quad (9)$$

where: n = number of emitters per plant; q_{min} and $\overline{q}$ = minimum and average emitter flow rate (L h^{-1}) along the lateral, respectively; CV = manufacturer's coefficient of variation.

In order to demonstrate versatility and easiness of the DIMSUB program, two case studies are described as carried out in a citrus orchard and an almond orchard in Valencia (Spain) (Figures 3A, 3B).

Citrus case study

The citrus orchard in Picassent (Lat. 39°20′59.5′′ N, Long. 0°28′16.67′′ W, altitude 58.5 m), Valencia (Spain), covers approximately 0.96 ha with a rectangular geometry of 128 × 75 m (Figure 3A).

For this example, a commercial dripperline with outside diameter (OD) of 16 mm (Internal diameter, ID = 14.2 mm) and 3.5 L h^{-1} emitters are used (coefficient of variation, CV < 7 %, ISO, 2004). Two laterals per plant row with emitter spacing of 1.0 m were installed. The laterals are on a downhill slope of –1 % while the manifold is on the level (0 % slope). In this example, an equivalent length of 0.25 m due to lateral local losses is considered according to manufacturer's recommendation.

Different alternatives were considered with different emitter types and feeding points to analyze the operating mode of the DIMSUB application (Table 1).

The first three alternatives use PC emitters to achieve wider pressure variations, since the emitter flow rate is always close to the nominal flow rate. In this case, engineers establish the allowable pressure head variation for the subunit considering the terrain slope, lengths of laterals and manifolds and distance between emitters. The range of pressure variation can influence in the initial pressure head and consequently energy consumption by the irrigation system.

Figure 3 – Case studies. A) Regular citrus orchard in Picassent; B) Irregular geometry of almond orchard in Chulilla (Valencia, Spain).

Table 1 – Study of various alternatives for designing subunits.

Case studies	Irrigation emitter type	Lateral Layout	Manifold Layout	Manifold pipeline size
PC 1	Pressure-compensating dripper	Extreme feeding point	Extreme feeding point	Single-pipe
PC 2	Pressure-compensating dripper	Extreme feeding point	Extreme feeding point	Two-diameter pipe
PC 3	Pressure-compensating dripper	Extreme feeding point	Paired Manifold in flat	Single-pipe size
NPC 1	Non-pressure compensating (x = 0.46)	Extreme feeding point	Extreme feeding point	Single-pipe size
NPC 2	Non-pressure compensating (x = 0.46)	Paired lateral with slope	Extreme feeding point	Single-pipe size
NPC 3	Non-pressure compensating (x = 0.46)	Paired lateral with slope	Extreme feeding point	Two-diameter pipe

The last three alternatives include NPC emitters, whose flow rate depends on their operating pressure, for pressure variation, which depends on the x exponent of the emitter, to be limited to achieve acceptably uniform irrigation. For instance, a non-pressure-compensating emitter with a discharge exponent around x = 0.5, with working pressure of 10.0 m (CV < 7 %), admits pressure head variations from 2.0 to 3.0 m to control the maximum flow rate variation within 10 to 15 %, respectively (Wu and Gitlin, 1983).

Computer application allows hydraulic variables to be selected and calculated from different feeding points in either the manifold or lateral pipes (Figure 4). The manifold and laterals can be fed from the extreme point, from a mid-point in flat terrain with no slope, or from an intermediate point in pipes with certain slope. Recently, some approaches have been proposed to find the optimal feeding point. Baiamonte et al. (2015), Ju et al. (2017) and Monserrat et al. (2018) presented analytical approaches determining the optimal length of paired drip laterals. DIMSUB with a step-by-step procedure calculates the required uphill and downhill pipe lengths to balance pressures in all emitters or laterals (Arviza and Palau, 2016).

The pressure-compensating interval for PC emitters varies for each manufacturer, usually ranging from 5.0 to 40.0 m. This interval allows a maximum pressure head variation of 35.0 m to ensure flow uniformity. However, a 5.0 m pressure head variation was established as design criteria, considering the plot characteristics, in alternatives PC1, PC2 and PC3, in order to get an adequate initial pressure head at the beginning of the subunit. Nevertheless, this value can be adjusted in DIMSUB establishing a minimum and maximum inlet operating pressure, as shown in DIMSUB (Figure 5).

Figure 5 shows the data entered for the first alternative, for which the program provides the hydraulic results for the irrigation lateral in box 1, including: initial flow rate, Christiansen coefficient, lateral head losses, pressure variation, α and β coefficients, required initial pressure, final extreme pressure, point of minimum pressure head and emission uniformity (EU) coefficient (eq. 9). Box 2 provides the lateral main calculation variables, such as number of emitters, lateral slope, maximum head losses admitted for manifold, local loss coefficient of the drippers.

The next step is to input the parameters required for designing and sizing the manifold.

The maximum pressure head variation established for the subunit ($\Delta H_{subunit}$) is then shared between the lateral and manifold head losses and slopes (eq. 7). DIMSUB begins by calculating lateral parameters. According to lateral head losses and differences in elevation, the remaining energy is available for manifold sizing.

In order to estimate the manifold length, manifold data are inserted, including slope of the terrain, number of plant rows, distance between laterals in the rows or distance from laterals of adjacent rows, as indicated in box 3 (Figure 5).

Based on the admissible pressure head variation in the subunit and laterals, DIMSUB calculates the parameters required to design the manifold pipe (box 4) (Figure 5): maximum pressure variation and maximum head loss remaining for the manifold (eq. 8), flow rate per lateral, total length and slope. It also estimates the minimum pipe diameter required to limit head losses within the admissible value.

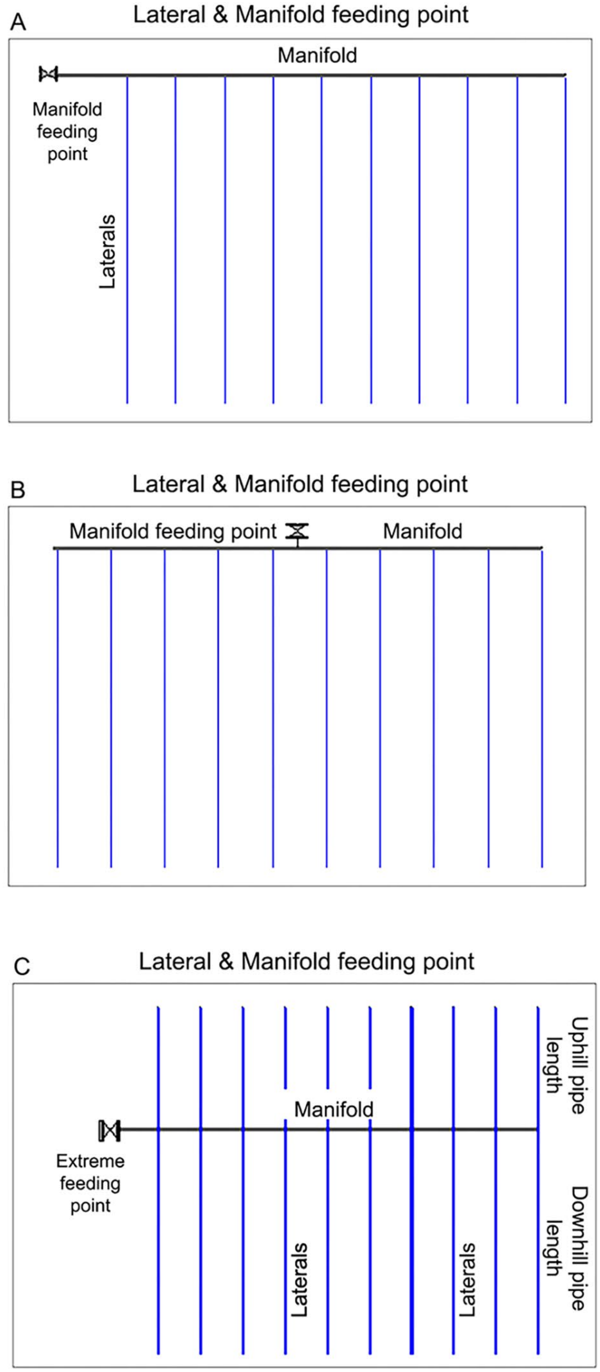


Figure 4 – Subunit feeding points: A) Laterals and manifold fed from an extreme point; B) Laterals fed from extreme point and manifold fed from mid-point; C) Laterals fed from intermediate point and manifold fed from extreme point.

Finally, box 5 (Figure 5) shows the results for the manifold pipe: nominal pipe diameter, internal diameter, real head loss, required initial pressure head, final pressure and pressure head variation in the manifold.

Almond orchard case study

This orchard is in Chulilla, Valencia (Spain) (Lat. 39° 56′ 56.73′′N, Longitude 0° 50′ 3.25′′W, altitude 387.8 m), and covers an area of approximately 0.75 ha. Figure 3B shows that the subunit geometry is irregular and the lateral length is variable as it follows the plot shape.

Designing and sizing irregular landscapes requires a special treatment, which can be carried out by outlining terrain geometry from an image or orthophoto in DIMSUB. The manifold network is graphically defined thus as water inlet points to the laterals and final points of laterals of different lengths (Figure 6).

The study considered a commercial lateral having outside diameter (OD) of 16 mm (Internal diameter, ID = 14.2 mm) with an integral pressure-compensating emitters discharging 3.5 L h^{-1}. The emitter spacing is 1.0 m with a double lateral per plant row. It is assumed that the insertion of each emitter produces the head losses corresponding to an additional pipe equivalent length of 0.25 m. This orchard has a 2.2 % uphill slope along the line of almond trees and –1.4 % crosswise from the water hydrant. The feeding point was from the extreme in the manifold and laterals (Figure 3B). Admissible pressure head variation was assumed equal to 5.0 m in all the alternatives considered.

This case of study evaluates the design results adjusting to the actual irregular shape (IS) of the subunit and those obtained with a simplified regular plot shape (RS). IS-1 and IS-2 use DIMSUB irregular subunit scheme to solve the case (Figure 6). RS-1 and RS-2 consider a simplified procedure designing a rectangular subunit of 104 × 107 m. Alternatives IS-2 and RS-2 are improved by a two-diameter tapered manifold.

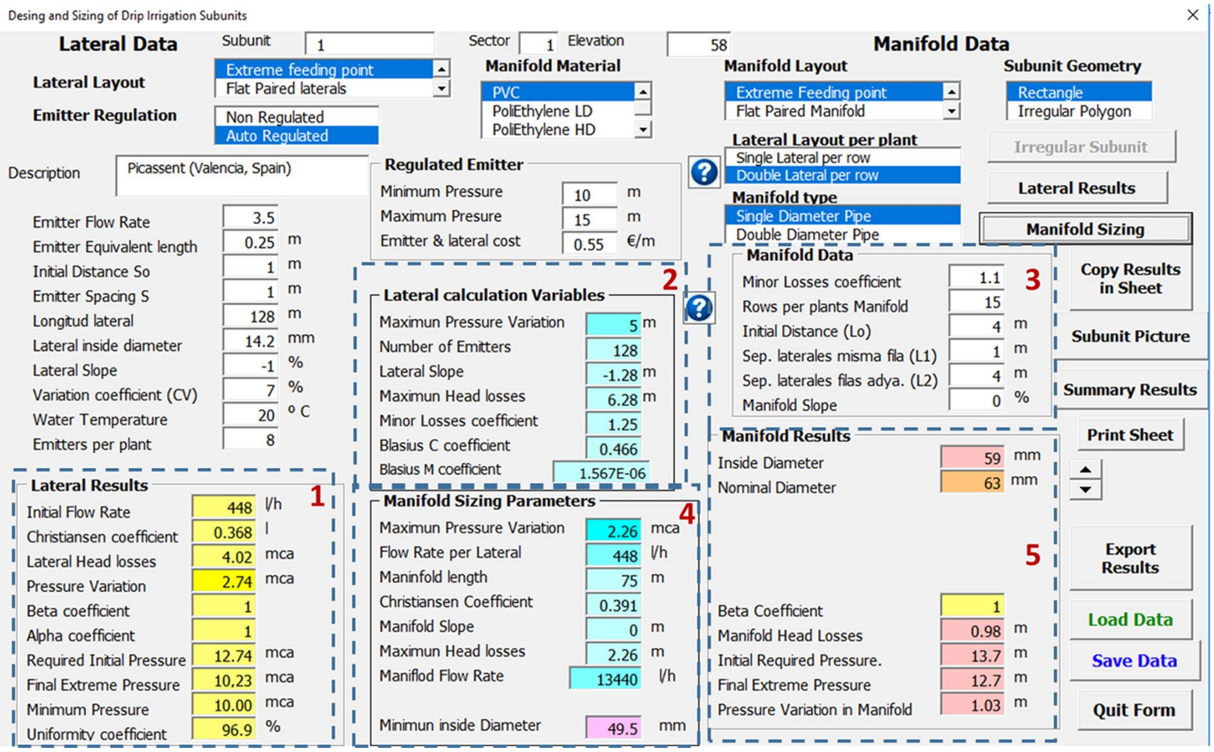
Results and Discussion

The proposed computer application is capable of efficiently analyzing different solutions for a given irrigation system and allowing the choice for the best pricewise and technical alternative.

DIMSUB can handle data files from the user form, as well as visualize a scheme of any type of lateral and manifold feed. An Excel sheet with the results can be printed and exported for further analysis of the irrigation distribution network. Moreover, the computer program measures the total lateral and manifold length and number of emitters for each subunit design analyzed and calculates the corresponding total cost in pipe material.

Results of the hydraulic analysis and cost of material are shown in Table 2 and Table 3, respectively, for all alternatives proposed in the case of the citrus orchard subunit.

This case study shows that, based on the subunit conditions, the use of non-compensating emitters offers better hydraulic and economic conditions. Lower initial subunit pressure is required (between 10.7 and 12.6 m) and the cost of laterals and emitters is considerably lower (44 % of cost reduction) (Tables 2 and 3).



Subunit 1
Sector 1
Elevation 58
Lateral Layout: Extreme feeding point
Emitter Regulation: Auto Regulated
Manifold Material: PVC
Manifold Layout: Extreme Feeding point
Subunit Geometry: Rectangle
Lateral Layout per plant: Double Lateral per row
Manifold type: Single Diameter Pipe
Description: Picassent (Valencia, Spain)

Emitter Flow Rate	3.5	
Emitter Equivalent length	0.25	m
Initial Distance So	1	m
Emitter Spacing S	1	m
Longitud lateral	128	m
Lateral inside diameter	14.2	mm
Lateral Slope	-1	%
Variation coefficient (CV)	7	%
Water Temperature	20	° C
Emitters per plant	8	

Regulated Emitter

Minimum Pressure	10	m
Maximum Presure	15	m
Emitter & lateral cost	0.55	€/m

Lateral calculation Variables

Maximun Pressure Variation	5	m
Number of Emitters	128	
Lateral Slope	-1.28	m
Maximun Head losses	6.28	m
Minor Losses coefficient	1.25	
Blasius C coefficient	0.466	
Blasius M coefficient	1.567E-06	

Manifold Data

Minor Losses coefficient	1.1	
Rows per plants Manifold	15	
Initial Distance (Lo)	4	m
Sep. laterales misma fila (L1)	1	m
Sep. laterales filas adya. (L2)	4	m
Manifold Slope	0	%

Lateral Results

Initial Flow Rate	448	l/h
Christiansen coefficient	0.368	l
Lateral Head losses	4.02	mca
Pressure Variation	2.74	mca
Beta coefficient	1	
Alpha coefficient	1	
Required Initial Pressure	12.74	mca
Final Extreme Pressure	10,23	mca
Minimum Pressure	10.00	mca
Uniformity coefficient	96.9	%

Manifold Sizing Parameters

Maximun Pressure Variation	2.26	mca
Flow Rate per Lateral	448	l/h
Maninfold length	75	m
Christiansen Coefficient	0.391	
Manifold Slope	0	m
Maximun Head losses	2.26	m
Maniflod Flow Rate	13440	l/h
Minimun inside Diameter	49.5	mm

Manifold Results

Inside Diameter	59	mm
Nominal Diameter	63	mm
Beta Coefficient	1	
Manifold Head Losses	0.98	m
Initial Required Pressure.	13.7	m
Final Extreme Pressure	12.7	m
Pressure Variation in Manifold	1.03	m

Figure 5 – DIMSUB hydraulic data display. PC (Pressure-compensating) emitter, 3.5 L h^{-1} (pressure range 5.0 - 40.0 m).

Table 2 – Results of hydraulic analysis of different alternatives studied.

Case studies	Maximum $\Delta H_{subunit}$	Flow rate	Required pressure head	Total lateral length	Manifold Outside Diameter (OD) D1/D2	Manifold length L1/L2
	m	L h^{-1}	m		mm	m
PC 1	5	13440	13.72	3840	63	75
PC 2	5	13440	14.85	3840	63 / 50	14 / 61
PC 3	5	13440	14.13	3840	40	74
NPC 1	3.26	13440	12.65	3840	75	75
NPC 2	2.17	13440	10.71	3840	75	75
NPC 3	2.17	13440	11.03	3840	75 / 63	9 / 66

PC = Pressure-compensating; NPC = Non-pressure compensating.

Table 3 – Costs of alternatives studied.

Case studies	Cost of lateral with integrated emitters[1]	Manifold pipe cost[2]	Subunit cost
	€		
PC1	2112.0	147	2259
PC2	2112.0	108.6	2221
PC3	2252.8	119.9	2373
NPC1	844.8	200.3	1045
NPC2	844.8	200.3	1045
NPC3	844.8	153.4	998

[1] Cost of pipe with non-pressure-compensating emitter is €0.22/m and €0.55/m for pressure-compensating emitter. [2] Cost of PVC manifold before installation: OD40 €1.62/m (PN 1.0 MPa), OD50 €1.33/m (PN 0.6 MPa), OD63 €1.96/m (PN 0.6 MPa) and OD75 €2.67/m (PN 0.6 MPa).

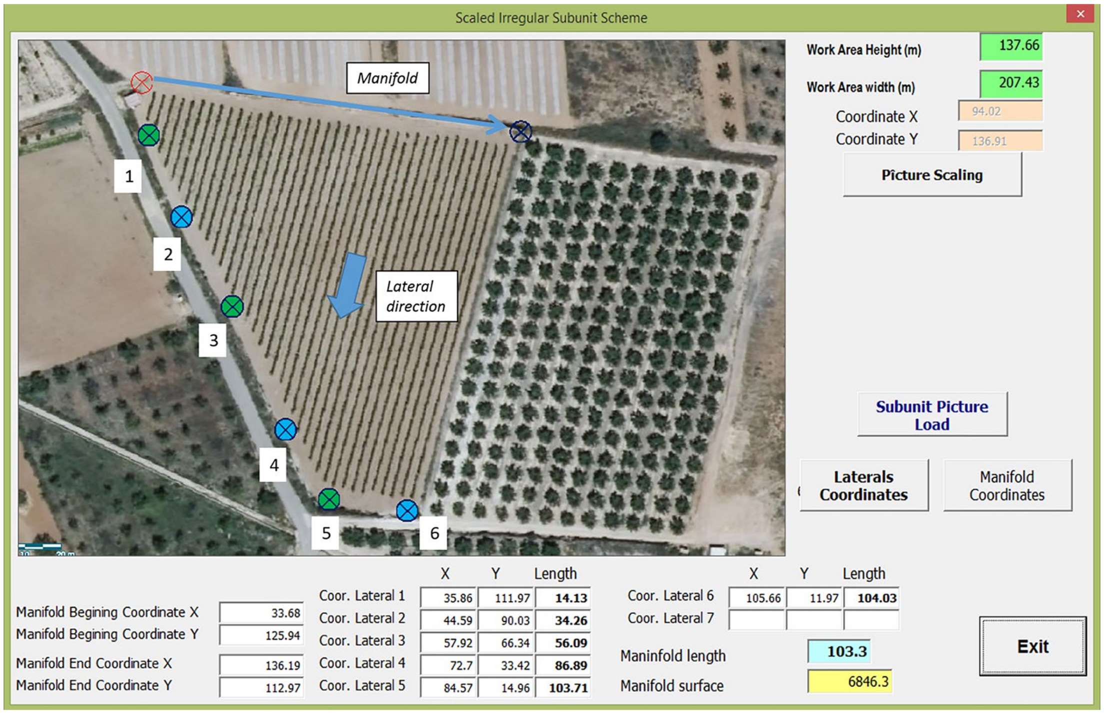
In the second case, irregular and regular geometries are studied in an almond orchard. The first cases analyzed (Table 4), IS-1 and IS-2, show the results obtained from the DIMSUB tool for designing irregular plots. In the regular geometry study, sizing is done with a single pipe size, while in the regular study, design is improved by adjusting the diameters with a two-diameter tapered manifold and achieving a more economical solution with lower energy requirements for the same established pressure variation.

This study shows that the application can deal with irregularly shaped plots by means of an image file that must be scaled to enable designing the subunit.

Table 4 – Technical and economical results.

Case studies	Flow rate	Required pressure head	Total lateral length	Manifold Outside Diameter (OD) D_1/D_2	Manifold length L_1/L_2	Emitters & Laterals cost [1]	Manifold pipe cost[2]	Subunit cost
	L h^{-1}	m	m	mm	m	€	€	€
Irregular subunit 1 (IS-1)	7838	15.5	2217	50	103	1219.4	137	1356.4
Irregular subunit 2 (IS-2)	7838	14.9	2217	50 / 40	78/ 25	1219.4	144	1363.4
Regular subunit 1 (RS-1)	12733	15.2	3601	63	103	1980.5	202	2182.5
Regular subunit 2 (RS-2)	12733	15.0	3601	63 / 50	48/ 55	1980.5	167	2147.5

[1] Cost of pipe with self-compensating emitter is €0.55/m; [2] Cost of PVC manifolds before installation: OD40 €1.62/m (PN 1.0 MPa), OD50 €1.33/m (PN 0.6 MPa) and OD63 €1.96/m (PN 0.6 MPa).



Work Area Height (m) 137.66

Work Area width (m) 207.43

Coordinate X 94.02

Coordinate Y 136.91

Manifold Begining Coordinate X 33.68

Manifold Begining Coordinate Y 125.94

Manifold End Coordinate X 136.19

Manifold End Coordinate Y 112.97

	X	Y	Length
Coor. Lateral 1	35.86	111.97	**14.13**
Coor. Lateral 2	44.59	90.03	**34.26**
Coor. Lateral 3	57.92	66.34	**56.09**
Coor. Lateral 4	72.7	33.42	**86.89**
Coor. Lateral 5	84.57	14.96	**103.71**
Coor. Lateral 6	105.66	11.97	**104.03**
Coor. Lateral 7			

Maninfold length 103.3

Manifold surface 6846.3

Figure 6 – Scaled irregular subunit scheme.

The results proved that adjusting the design to the terrain geometry appreciably improves the solution and reduces costs, due to the adjustment of manifold pipe sizes. Furthermore, multioutlet tapered manifolds in long pipe runs, in both IR-2 and RS-2, achieve lower energy and cost requirements at the subunit entrance.

Conclusions

DIMSUB is a computer application that can be used as a decision support tool. This program can aid in designing and sizing precisely and rapidly individual irrigation subunits. The lateral and manifold pipes in a subunit can be graphically drawn for any type of geometry.

Irregular geometries, sloped terrains and different feeding points of laterals and manifold can be easily studied to achieve accurate results and evaluate design alternatives.

Case studies have been evaluated with DIMSUB, showing the main performance variables of irrigation systems that allow technicians to make decisions. Results obtained from this application have been supported by real cases where engineers designed and executed irrigation subunits successfully.

Authors' Contributions

Conceptualization: Arviza J.; Palau C.V.; Manzano J; Methodology and Computer application programming: Arviza J.; Data acquisition and analysis: Palau, C.V.; Balbastre, I.; Writing and editing: Palau, C.V.; Manzano J.

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Appendix

DIMSUB is available by contacting jarviza@agf.upv.es.