WATER REQUIREMENTS, IRRIGATION EVALUATION AND EFFICIENCY IN TENERIFE'S CROPS (CANARY ISLANDS, SPAIN)

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ABSTRACT

This study, carried out between October 2004 and November 2005 on the island of Tenerife, covers: (1) characterization of the irrigated crops and quantification of the gross irrigation requirements (GIRs) of each crop using surveys; (2) field evaluation of drip/micro, spray and sprinkle irrigation systems to obtain global distribution uniformity (*DU*) as indicated by the Cal Poly ITRC (Irrigation Training and Research Centre, California Polytechnic State University, San Luis Obispo, California, USA); (3) analysis of on farm irrigation efficiency using local climatic data; and (4) inclusion of this data into a Geographic Information System (GIS).

Crop GIRs show high deviations mainly because of the multiple microclimate conditions on the island, the irrigation methods used, the crop systems (greenhouses, etc) and the irrigation management.

Field evaluation provided an average *DU* of 0.83 in drip/micro and spray irrigated banana crops, 0.69 in sprinkle irrigated ones, 0.58 in sprinkle irrigated horticulture and 0.81 for tomato crops (100% drip). Data showed that approximately 30% of the non-uniformity was due to pressure differences in the irrigation system, 3% due to unequal drainage, 7% due to unequal application rates, and 60% was due to other causes (which include manufacturing variation, plugging, and wear).

Irrigation efficiency is around 80% in drip irrigated tomato and banana crops and 75% in sprinkle systems. Data showed that efficiency is slightly lower in greenhouses and mesh greenhouse crops than in non-protected crops basically due to the fact that although protected crops require less water, they receive an equal quantity of water. Inclusion of the data into a GIS makes possible a high level of agronomic water consumption control on the island.

INTRODUCTION

To know the precise agricultural water consumption and the main characteristics of the irrigation systems on an island such as Tenerife (which is similar in its hydrologic behaviour to a continental basin) it is necessary to use this resource properly and to create plans oriented to increase its efficiency.

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The principal purpose of this study is the characterization of the irrigated lands in Tenerife, to quantify the gross irrigation requirements (GIRs, in m³/ha and year) of the main crops as well as their statistical distribution by areas and irrigation methods. Furthermore, the average distribution uniformity (*DU*) of the irrigation systems has been determined, detecting the main causes that lead to the lack of uniformity. This data is based on field evaluations in irrigation systems.

Once this first field-phase was completed, the study moved to the estimation, by using climatic data, of the degree of adequacy of the actual consumptions to the water needs of each crop. On farm irrigation efficiencies were estimated for different irrigation methods, crops and areas of the island.

Finally, the resulting GIRs were applied to the existing irrigated land surfaces on the island, using GIS tools and providing the global water consumption of the island, classified for different areas.

In the same way, the present GIRs were compared to the ones appearing in a previous study of agricultural water consumption, which was published 25 years ago (ICSA-GALLUP S.A.,1981), with the final purpose of analyzing the development of irrigation technology evolution on the island during this period.

METHODOLOGY

Study based on surveys

The characterization of irrigated lands and the determination of the GIRs have been made by carrying out a survey on the water users (farmers). During the survey, the installation of the irrigation system and its control system were examined. The water users were asked about their management and maintenance habits, to perform measurement of plant spacing, flow rate of emitters, work pressures, pipe diameters and lengths, etc.

Surveys were made during the 2004-05 campaign and the water-user answers on GIRs, number of crops and harvest duration (in the case of seasonal crops), management criteria and irrigation practices refer to the previous campaign.

The number of surveys needed to determine the parameters of study with enough accuracy was established taking into account the distribution of the variable GIRs that existed in the population, defined by the variation derived from a previous study (ICSA-GALLUP S.A.,1981)

One thousand five (1005) surveys were performed (in the 8 agro-climatic areas in which the island can be divided, Fig 1), of which 959 were analysable (95,4%). The GIR was considered valid in 859 (85,5%) of these surveys. The farms were chosen at random over the crop surface area with or without greenhouses limited by the GIS 2004 Crop Map made by the Exmo. Cabildo de Tenerife (ECIT).

With the final aim of guaranteeing that the geographical distribution of surveys expressed the geographical distribution of each crop, rural GIS crop maps were used to determine the number of surveys to be carried out for a given surface area and the number of surveys per crop.

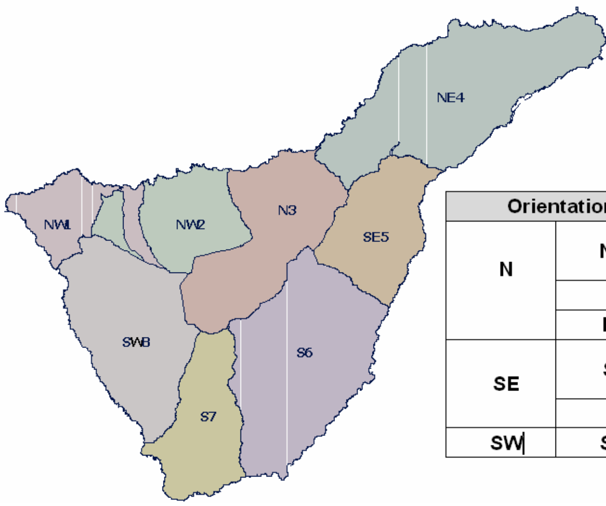
In order to choose the farm to survey, the following criteria were adhered to:

a. The farm could only have one crop and had to have only one irrigation method.

b. The farm had to be homogeneous (e.g.: any surface area with or without greenhouses).

c. The farm could not be adjacent to another that had already been surveyed.

d. The farm was never chosen in relation to the irrigation method used, because one of the aims of the survey was to provide the frequencies of each irrigation method.



Orientation		Zones
N	NW	Zone 1 (Isla Baja)
		Zone 2 (Icod)
	N	Zone 3 (Valle de La Orotava)
	NE	Zone 4 (Tacoronte-Acentejo, Anaga)
SE	SE	Zone 5 (Valle de Güimar)
		Zone 6 (SE Zone)
	S	Zone 7 (Southern Zone)
SW	SW	Zone 8 (SW Zone)

Figure 1. Agro-climatic areas on Tenerife

Each one of the surveyors had equipment consisting of maps of the area, an electronic note-book (PDA, Figure 2) with GPS to locate his own position and the farms to survey as well as to accede to the Map of crops and ortho-photos. To minimize the possibility of inaccurate answers of the farmers about the crop surface area, once the field was surveyed, this parameter was digitalized using the PDA.

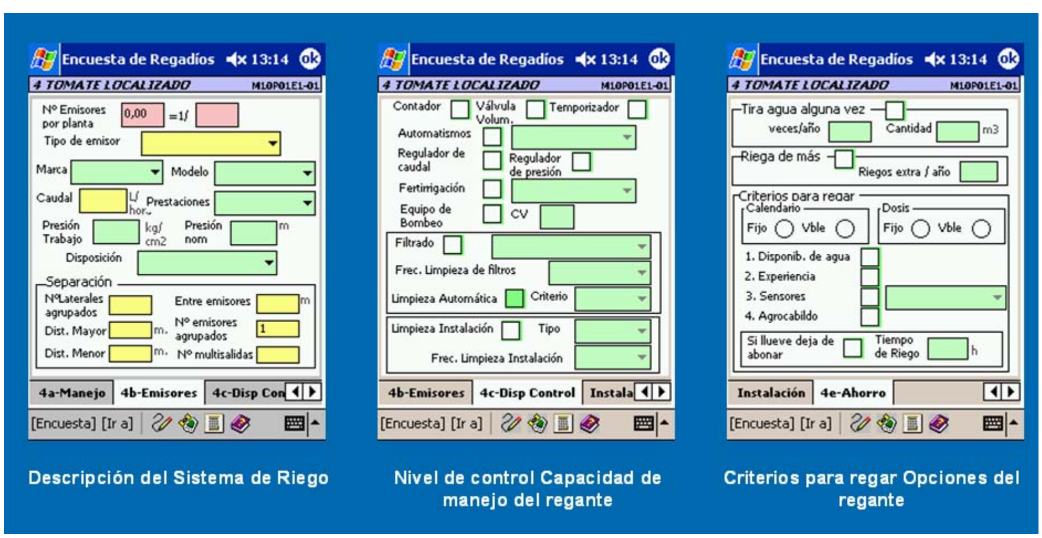


Figure 2. Surveys. Several images from the computer application loaded onto the PDA

Surveys were carried out using a computer application loaded onto the PDA (Fig.2) able to operate with the input data. This was useful for detecting possible mistakes in the water-user answers and to contrast them with complementary equations and valid shift ranks also loaded onto the PDA.

The application automatically created a data base with a new register for each one of the completed surveys. Later on, this data base was downloaded to the principal data base, which was incorporated to the GIS for its analysis.

The staff who carried out the field work (surveys and irrigation evaluations) was Agricultural Engineers. Before this study took place, they were given a specific training course, as recommended by the IRTC (Irrigation Training and Research Centre of the Polytechnic University of California).

Precise knowledge of rainfall during the period in which this study was elaborated (2004) is always required to determine if the year was dry, average or a wet one. In order to determine this, a study based on data from the National Meteorological Institute network rainfall stations on the island was carried out.

Evaluation of the Irrigation Systems

The irrigation system evaluation was developed according to the ITRC method (Fig. 3). One hundred forty two (142) irrigation evaluations were made, 105 were drip/micro and spray systems and 37 were sprinkle systems.

In order to perform the evaluations, the farms with their GIR close to the average value of the agro-climatic area were selected within the survey.

In contrast with the Merrian & Keller method (MERRIAN, 1978), the procedure proposed by the ITRC estimates the global *DU* on the whole farm. Also, this method is able to discriminate different distribution uniformities (*DU*) due to different factors, in such a way that the analysis of them provides the real causes that lead to non-uniformity.

The following factors are taken into account:

a. Lack of uniformity due to pressure differences in the irrigation system ($DU_{\Delta P}$)

$$DU_{\Delta P} = \left(\frac{P_{25\%}}{P} \right)^x \tag{1}$$

Where: $P_{25\%}$= Average low-quarter pressures; P= Average of the pressures; x= Discharge exponent of the emitter.

b. Lack of uniformity due to unequal application rates (uneven spacing between plants and/or emitters). (DU_{ed})

$$DU_{ed} = \frac{LAS_{\min}}{LAS_{weav}} \tag{2}$$

Where: LAS_{min}= Lowest weekly depth of water applied (mm) on a plot of the farm; $LAS_{we.av}$= Average weekly depth or water, applied (mm) on the whole farm, weighted per surface area.

c. Lack of uniformity due to unequal drainage of the emitter once the irrigation has finished (DU_{dd})

$$DU_{dd} = 1 - \left(\frac{t_{extra}}{t_{avg}} \right) \times \% Surf.affect. \tag{3}$$

Where: t_{extra}= Extra drainage time (min) once the irrigation has finished; t_{avg} = Average irrigation time (min); *% Surf. affect*:= Percentage of surface area affected by extra drainage.

d. Lack of uniformity due to other causes (which include manufacturing variation, plugging, and wear), DU_{other}.

$$DU_{other} = 1 - \frac{1}{\sqrt{e}} + \frac{1}{\sqrt{e}} \times \left(Avg. \frac{q_{25\%}}{q_{avg}} \right) \tag{4}$$

Where: $q_{25\%}$= Average low-quarter flow rate (L/h); q_{avg}= Average flow rate (L/h); e = Number of emitters measured per element area.

Figure 3. Irrigation evaluation in a drip irrigated tomato crop in Tenerife

From these partial *DU*s, the global *DU* (DU_{global}) of the irrigation system is estimated using Equation 5. The estimation is based on the element area concept, known as the maximum area in the field that requires water, but within which the variation of distributed water is not important (BURT et al,1997).

$$DU_{global} = 1 - \sqrt{(1 - DU_{\Delta P})^2 + (1 - DU_{ed})^2 + (1 - DU_{dd})^2 + (1 - DU_{other})^2} \tag{5}$$

Estimation of on farm irrigation efficiency

The theoretical on farm irrigation efficiency was estimated taking into account the following data:

a. The climatic information received by the agro-meteorological stations built by the ECIT on farms placed in the main agricultural areas of the island.
b. The real GIR and the management factor of the water user determined for crops and areas of the island
c. The *DU* obtained for crops and areas of the island, based on irrigation evaluations
d. The leaching requirements based on the water salinity of the samples taken on the farm during irrigation evaluation.

On farm irrigation efficiency is defined as "the ratio of the average depth of irrigation water that is beneficially used to the average depth of irrigation water applied, expressed as a percentage" (BURT et al, 1997). It was determined by the following equation:

$$Er = \frac{Nb}{Vf} \tag{6}$$

Where: Er = On farm Irrigation efficiency; Nb = Depth of irrigation water that is beneficially used (mm); Vf = Average depth of irrigation water applied (mm).

Vf was determined from the average GIR weighted per farm size, obtained in the survey phase. In order to get Nb, it was needed to determine the crop evapotranspiration (ETc) and the leaching requirements (LR), discounting rainfall (effective precipitation).

$$Nb = \frac{ETc - Pe}{1 - LR} \tag{7}$$

ETc was estimated using Equation 8.

$$ETc = ETo \cdot Kc \tag{8}$$

Where: ETc = Crop evapotranspiration; ETo = Reference crop evapotranspiration; Kc = Crop coefficient. ETo was estimated by the FAO Penman-Monteith equation, based on average monthly values of meteorological data.

Wind speed in net houses was estimated in relation with MÖLLER et al. (2003) in such a way that it could later be used in the FAO Penman-Monteith equation, following FAO advice (ALLEN et al, 1998).

For the crop coefficient (Kc) the values proposed by the FAO in DOOREMBOS (1977) were considered, except in the case of banana plantations where unpublished data determined by the Agricultural Service of ECIT were used.

For the estimation of effective precipitation (Pe) the equations presented by the US Bureau of

Reclamation (SMITH, 1993) were used.

$$Pe = \frac{P}{125}\left(125 - 0{,}2\,P\right) \text{ for P < 250} \tag{9}$$

Where P = monthly precipitation (mm).

The leaching requirement (LR) was determined from the equations in DOOREMBOS (1977) according to irrigation method. For the EC value, the average value of EC, based on the samples of water taken in each one of the irrigation evaluations made on farm, was chosen.

For the *DU* value, the average value of the DU_{global}, obtained in the irrigation evaluations, was taken.

Once *Er* (Equation 6) was estimated, it was divided in the several factors in which it is composed following this equation:

$$E_r = C_{mg} \times (1 - E) \times DU_{global} \tag{10}$$

Where: C_{mg}: Management factor (%); *E = Surface losses, evaporation during irrigation in the case of spray or sprinkle irrigation (%).* C_{mg} gives us an idea of how the water user manages the irrigation system, and it can only be determined (Equation 10) once we know the rest of the values. This management factor comprises the losses by percolation as well as those caused by the water user's irrigation management.

The losses by evaporation (*E*) were considered null in the case of drip irrigation. Thus, *Er* factors were completely defined for every component, making clear which factor(s) could be affecting it negatively and their level of intensity.

In the same way, the maintenance factor, C_{mn} (RODRIGO et al, 1992) was estimated, which gives us an idea of the use that the installation receives. This is estimated by Equation 11. In this equation DU_{actual} is the DU_{global} obtained in the irrigation system evaluations, and $DU_{potential}$ is the highest value of *DU* which is possible to achieve with each one of the irrigation methods. These values, shown in Table 1, have been established based on the results obtained in the present study.

$$C_{mn} = \frac{UD_{actual}}{UD_{potential}} \tag{11}$$

Following this procedure, the necessity to correct the irrigation management habits can be distinguished from the necessity to improve the installation maintenance, and it is even possible to measure the advantages that would produce a hypothetic change in the irrigation system.

Table 1. Results for DU potential for different emitter types in Microirrigation

Irrigation System	Emitter Type	DU potential
Microirrigation	PC and anti drain	97 %
	PC	95 %
	Conventional	90 %

PC = pressure compensating emitter

Determination of the global water consumption of Tenerife: Changes in the last 25 years

The GIRs obtained were incorporated to a GIS that contained the crop map of Tenerife, designed by the ECIT in 2004, constituting a new layer of information. The combination of the data included in both layers made it possible to obtain the global water consumption of Tenerife, divided into crops and areas. This information will be completely necessary in the elaboration of the next Hydrologic Planning of Tenerife (2008).

In the same way, the present GIRs were compared to the ones which appeared in a previous study on agricultural consumption, which was published 25 years ago (ICSA-GALLUP S.A.,1981), with the final purpose of analyzing the development of irrigation technology on the island during that period.

RESULTS, DISCUSSION AND CONCLUSIONS

Study based on surveys

The methodology used in the survey phase, that allows verification and contrast of the results in the field and with the water-user interviewed, allowed us to correct many surveys that would be considered invalid due to multiple causes. (Surveys were filled in using a computer application loaded onto the PDA, able to operate with the input data. This is useful to detect possible mistakes in the water-user answers and to contrast them with complementary equation and valid shift ranks loaded onto the PDA).

The digitalization of the limits of the crop surface area, which was carried out in situ for each one of the surveyed farms (adding these surface areas to a GIS), was absolutely necessary for estimating the GIRs with maximum accuracy.

The use of the PDA during the survey-phase did not only save time and resources, it also avoided transcription mistakes that would be inevitable with traditional methods.

The use of the polygon GIS crop maps in the distribution of the surveys (using GIS tools and based on the percentage of crop surface area that each polygon covered in relation to the whole crop surface area) guaranteed that the geographical distribution of the surveys corresponded to the geographical distribution of each crop. Furthermore, this method made the field work and the control of its efficiency easier.

The adoption of several homogeneity criteria was necessary to consider one farm adequate for being surveyed, because the purpose of this study is to apply the obtained results to the rest of the population and to detect differences in crops, crop systems and irrigation methods.

Irrigation evaluations: ITRC Methodology

The ITRC method, which determines the weight of each factor when referring to the lack of global distribution uniformity, is ideal for the characteristics of the irrigated lands in Tenerife, where diverse parameters co-exist and where it is completely necessary to establish their influence. For instance, the uneven topography of the island, which results in farms with important unevenness (terraces at different levels), affects the irrigation uniformity through pressure differences and the uneven drainage in the process of the system evacuation once the irrigation is finished.

The influence of farm topography over irrigation evaluation is considered a key point of study and it must be analysed, trying not to leave it hidden among other factors.
It has been shown that the ITRC method underestimates the DU in special circumstances that are going to be explained. In relation with this fact, additional estimations and actions have been made as alternatives to the ITRC method. These additional modifications were executed after taking into account their convenience or not in each case:

The non-uniformity caused by an unequal density of emitters per surface area: unequal spaces between plants and emitters (DU_{ed}), is considered a valid parameter, when the irrigation is produced with an invariable number of emitters per plant and in cases of high percentages of shaded areas by the crop. However, when the soil plant covering was less than 70% (e.g. some banana plantations in paired lines with wide aisles), the water demand varied with the density of plantation and in these cases it has been observed that, applying rigorously the ITRC procedure the distribution uniformity was under-estimated due to unequal spaces (DU_{ed}).

This is due to the fact that the uniformity criteria chosen are only based on the applied water depths (mm) and it doesn't take into account the possible necessity of applying different depths in areas planted with different density (using a different number of emitters or using different application times). In these cases, and always after considering the convenience of the practice of irrigation application, the penalizations imposed by the methodology have been diminished, using, in order to determine the DU_{ed} , the water applied per plant (element) and not the water depth applied.

Figure 4. Greenhouse tomato crop located in terraces.

With reference to the spray and sprinkle irrigation systems, it has been detected that the ITRC procedure doesn't consider the cases in which the farmer, aware of the flow rate differences that exist among the irrigation plots that work under different pressures, corrects it by modifying the irrigation time applied in each one of them. In those circumstances, although the irrigation system shows a deficient DU_{global} (induced by a low $DU_{\Delta P}$), the application of water to the crop does not present such an unfavourable *DU*. In these cases the penalizations imposed by the methodology have been diminished, always after considering the convenience of the management practice, using the real average flow rate of the sprinkles and the application irrigation time in each plot.

Gross irrigation requirements (GIRs) determined

The results of the average values of GIR for each crop, irrigation method, crop system and area, are shown in Tables 2a and 2b.

A systematic analysis of variance for the GIRs obtained for the different areas of study, irrigation methods and main crop systems (with or without greenhouses, with or without soil) has been useful to detect significant differences.

The differences among the GIRs obtained for each sub-group must not be associated only with the irrigation method employed or to the crop system. These values are the result of a combination of multiple factors that directly influence the water consumption. One of those factors is the annual period in which the field is reaped (duration of each crop multiplied by the number of crops reaped successively in the same field in a year), whose average value appears under seasonal crops in Table 2b.

There are some other factors that have influence over the GIRs, they appear in the data base created for the surveys, although they are more difficult to take into account because the segregation of their own samples would diminish the number of surveys related to each option: micro-climatic area (sunny, shading, etc), farm size, irrigation management habits, degree of maintenance of the installation, etc. Also, there are other kinds of factors that could not even be quantified in the present study, but they affect the GIRs in the same way as other factors do (the production obtained, the dedication to maintenance of the farm, etc).

An inversely proportional relationship between the surface area of the field and the variance factor (VF) of the GIR has been detected in almost every one of the studied crops. That is to say that the GIRs obtained show a wider dispersion in small-sized farms in contrast with those of a bigger surface area, which present values that are more in harmony with the average. See Figure 5.

It has been verified that in many areas and crops there are not significant differences between the water consumption in the open air and in greenhouses. This fact influenced, on a low scale, in the efficiency of the irrigation in crops with greenhouses, mainly in banana plantations (refer to the conclusions related to on farm irrigation efficiency).

Banana crops: the GIRs obtained, independently of the irrigation method, have not suffered significant changes in the last 25 years. The GIR that has suffered a more significant change was that for spray irrigation, which has diminished by 10% since the previous study (ICSA-GALLUP,1981).

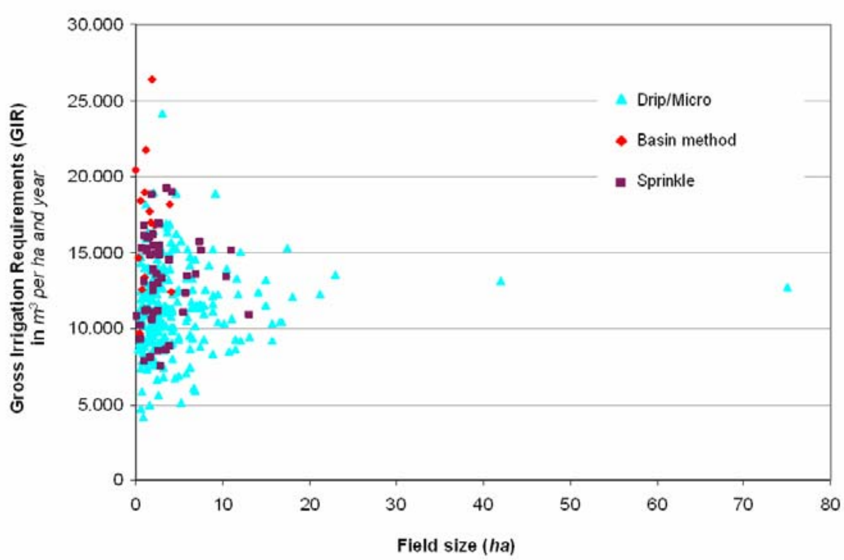


Figure 5. GIR (m^3/*ha and year*) vs. field area (*ha*) in banana plantations for each irrigation method used (drip/micro, spray and level bedded basin).

The average GIR for banana plantations and tomato crops in Tenerife has diminished if we compare the present data with the previous estimations in 1981 (ICSA-GALLUP). Basically, this fact has been caused by the substitution of almost all flood irrigation systems (level bedded basin in banana plantations and furrow irrigation in tomato crops) in benefit of more efficient methods of water use (drip/micro and spray irrigation).

Table 2a. Average GIRs for irrigation method, crop system and number of surveys made

CROP	Irrigation Method	Crop system	AREA 1		AREA 2		AREA 3		AREA 4	
			m^3/ha· year	Nº	m^3/ha· year	Nº	m^3/ha· year	Nº	m^3/ha· year	Nº
BANANA	Basin	Open Air	12,544	1	13,350	1	18,186	9	14,265	4
	Spray	Greenhouse	-	0	-	0	-	0	8,603	2
		Open Air	10,927	2	13,072	3	12,637	8	12,790	3
		AVERAGE	10,927	2	13,072	3	12,637	8	10,983	5
	Drip/Micro	Greenhouse	10,844	10	10,265	3	-	0	8,964	8
		Open Air	11,066	55	8,975	6	8,544	28	10,696	10
		AVERAGE	11,020	65	9,228	9	8,544	28	9,717	18
	AVERAGE		11,020	68	9,611	13	10,796	45	10,170	27
TOMATO	Drip	Open Air	-	0						
		Greenhouse	6,907	1						
		Soilless system (greenhouse)	-	0						
	AVERAGE		6,907	1						
VINEYARD	Drip	Open Air	465	5	1,564	5	725	11	804	30
	Hose	Open Air	-	0	-	0	-	0	995	4
	Furrow	Open Air	-	0	-	0	-	0	960	7
	Basin	Open Air	-	0	-	0	-	0	2,554	1
	AVERAGE		465	5	1,564	5	725	11	821	42
CROP	Irrigation Method	Crop system	AREA 5		AREA 6		AREA 7		AREA 8	
			m^3/ha· year	Nº	m^3/ha· year	Nº	m^3/ha· year	Nº	m^3/ha· year	Nº
BANANA	Basin	Open Air	-	0	-	0	-	0	-	0
	Spray	Greenhouse	-	0	-	0	13,672	7	14,211	3
		Open Air	-	0	-	0	15,610	4	14,169	18
		AVERAGE	-	0	-	0	14,435	11	14,175	21
	Drip/Micro	Greenhouse	11,725	9	9,964	3	11,818	33	12,654	34
		Open Air	7,941	1	12,374	1	11,099	6	14,577	30
		AVERAGE	11,623	10	10,329	4	11,765	39	13,684	64
	AVERAGE		11,623	10	10,329	4	12,028	50	13,795	85
TOMATO	Drip	Open Air			-	0			6,843	3
		Greenhouse			4,518	24			6,128	30
		Soilless system (greenhouse)			4,776	4			-	0
	AVERAGE				4,594	28			6,148	33
VINEYARD	Drip	Open Air	1,797	13	750	12	789	8	1,547	5
	Hose	Open Air	-	0	-	0	-	0	-	0
	Furrow	Open Air	-	0	-	0	-	0	-	0
	Basin	Open Air	-	0	-	0	-	0	-	0
	AVERAGE		1,797	13	750	12	789	8	1,547	5

Distribution of irrigation methods

The present study has allowed us to establish the existing percentages of each irrigation method for each crop and in each location of the island (Table 3), which was previously unknown information and which constitutes a completely necessary tool in order to estimate the global water demand based on crop surface areas and GIRs.

Thanks to a sample of 100% farms in some model areas, it was verified that the obtained percentages of each irrigation method (chosen at random) coincided with the actual distribution of them in the area. In Table 3 these percentages appear for each area and main crop, distinguishing between greenhouse and open air crops.

Irrigation uniformity

Irrigation uniformity in the drip/micro systems by crops: The average global *DU* of the drip/micro irrigation systems in Tenerife, determined by the ITRC procedure is over 80%: 83% in banana plantations and 81% in tomato crops.

Compared with the results of the evaluations made by the California State Polytechnic University, San Luis Obispo, California, USA (Cal Poly) in 260 farms from Central California, which provided an average global DU of 85% in drip and 80% in spray (BURT,2005), the values obtained in Tenerife in tomato farms and banana plantations can be considered as adequate ones.

The frequency of renovation of the irrigation systems and the relatively small size of the farms (in relation with the evaluated Californian farms) constitute the key points to these good uniformities obtained in Tenerife.

Table 2b. Average GIRs per irrigation method and crop system and number of surveys made

CROP	Irrigation Method	Crop System	NORTHERN AREA			SOUTHERN AREA		
			m^3/ha·year	Nº	*Average Growing Period (months/year)*	m^3/ha·year	Nº	*Average Growing Period (months/year)*
POTATOES	**Sprinkle**	Open Air	5,533	*39*	*6.4*	3,769	*40*	*4.6*
	Drip/Micro	Open Air	6,092	*7*		4,711	*7*	
	Hose	Open Air	10,542	*4*		4,560	*7*	
	Furrow	Open Air	3,091	*22*		4,109	*6*	
	AVERAGE		**5,399**	*72*		**3,839**	*60*	
VEGETABLE ROW CROPS (may include potatoes)	**Sprinkle**	Greenhouse	3,508	*2*	*10.49*	7,000	*1*	*9.84*
		Open Air	6,561	*28*	*9.35*	4,220	*3*	*8.70*
		AVERAGE	6,004	*30*	*9.42*	5,284	*4*	*8.98*
	Drip/Micro	Greenhouse	8,706	*23*	*11.16*	7,234	*13*	*7.80*
		Open Air	7,194	*11*	*8.57*	7,910	*12*	*6.55*
		AVERAGE	8,088	*34*	*10.32*	7,602	*25*	*7.23*
	Hose	Open Air	12,243	*8*	*10.55*	-	*0*	-
	Furrow	Open Air	5,029	*8*	*9.52*	-	*0*	-
	AVERAGE		**6,693**	*80*	*9.39*	**6,821**	*29*	*7.01*
SUBTROPICAL TREES AND CITRUS	**Basin**	Open Air	5,582	*1*		13,897	*2*	
		Greenhouse	-	*0*		-	*0*	
		AVERAGE	5,582	*1*		13,897	*0*	
	Sprinkle	Open Air	5,986	*5*		7,347	*1*	
		Greenhouse	-	*0*		-	*0*	
		AVERAGE	5,986	*5*		7,347	*1*	
	Drip/Micro	Open Air	3,518	*17*		5,167	*19*	
		Greenhouse	7,661	*5*		8,036	*10*	
		AVERAGE	4,363	*22*		6,187	*29*	
	AVERAGE		**4,830**	*28*		**6,492**	*32*	

CROP	Irrigation Method	Crop System	NORTHERN AREA			SOUTHERN AREA		
			m^3/ha·year	Nº	*Average Growing Period (months/year)*	m^3/ha·year	Nº	*Average Growing Period (months/year)*
FLOWERS AND ORNAMENTAL PLANTS	**Sprinkle**	Open Air	6,541	*8*		-	*0*	
		Greenhouse	7,721	*3*		-	*0*	
		AVERAGE	6,801	*11*		-	*0*	
	Drip/Micro	Open Air	5,268	*11*		9,407	*3*	
		Greenhouse	8,868	*16*		13,564	*4*	
		AVERAGE	6,894	*27*		10,851	*7*	
	Furrow	Open Air	10,800	*1*		-	*0*	
	Drip	Soilless system (greenhouse)	9,581	*1*		-	*0*	
	AVERAGE		**7,005**	*40*		**10,851**	*7*	
SMALL FAMILY ORCHARDS	**Sprinkle**	Open Air	5,635	*7*		1,571	*1*	
	Drip/Micro	Open Air	5,643	*5*		3,263	*5*	
	Hose	Open Air	2,941	*18*		3,410	*3*	
	Furrow	Open Air	4,680	*15*		11,520	*1*	
	Several	Open Air	8,659	*18*		6,010	*1*	
	AVERAGE		**7,005**	*40*		**10,851**	*7*	

In the case of banana plantations we have to add the great number of emitters per plant (between 6 and 12), which produces an increase of the global *DU* although the emitter CV.
In the tomato crops we have to add the quality of the drip emitters used, that in 95% of the cases were PC and in 85% were anti-drain.

The average global *DU* obtained in drip/micro irrigation systems employed in subtropical trees and citrus is 78%, slightly lower than in banana plantations and tomato crops because of the existence of some deficiently attended farms.

Table 3. Distribution of the irrigation methods by location and crops

CROP	Irrigation Method	Crop System	Northern Area	Southern Area	CROP	Irrigation Method	Crop System	Northern Area	Southern Area
			% surface	% surface				% surface	% surface
FAMILY HORTICULTURE	**Sprinkle**	Open Air	17.5%	14.3%					
	Microirrig.	Open Air	12.5%	71.4%	POTATO CROP	**Sprinkle**	Open Air	54.2%	66.7%
	Hose	Open Air	45.0%	42.9%		**Microirrig.**	Open Air	9.7%	11.7%
	Furrow	Open Air	37.5%	14.3%		**Hose**	Open Air	5.6%	11.7%
	Several	Open Air	45.0%	14.3%		**Furrow**	Open Air	30.6%	10.0%
	TOTAL		100.0%	100.0%		**TOTAL**		100.0%	100.0%
SUBTROPICAL TREES	**Surface**	Open Air	3.6%	6.3%	INTENSIVE HORTICULTURE	**Sprinkle**	Greenhouse	2.5%	3.4%
		Greenhouse	0.0%	0.0%			Open Air	35.0%	10.3%
		TOTAL	3.6%	0.0%			TOTAL	37.5%	13.8%
	Sprinkle	Open Air	17.9%	3.1%		**Micro Irrigation**	Greenhouse	28.8%	44.8%
		Greenhouse	0.0%	0.0%			Open Air	13.8%	41.4%
		TOTAL	17.9%	3.1%			TOTAL	42.5%	86.2%
	Micro Irrigation	Open Air	60.7%	59.4%		**Hose**	Open Air	10.0%	0.0%
		Greenhouse	17.9%	31.3%		**Furrow**	Open Air	10.0%	0.0%

		TOTAL	78.6%	90.6%		**TOTAL**	100.0%	100.0%
	TOTAL		100.0%	100.0%				
FLOWERS AND ORNAMENTAL PLANTS	**Sprinkle**	Open Air	20.0%	0.0%				
		Greenhouse	7.5%	0.0%				
		Total	27.5%	0.0%				
	Micro irrigation	Open Air	27.5%	42.9%				
		Greenhouse	40.0%	57.1%				
		Total	67.5%	100.0%				
	Furrow	Open Air	2.5%	0.0%				
	Microirrig. Hydroponic	Open Air	2.5%	0.0%				
	TOTAL		100.0%	100.0%				

The global *DU* in the drip/micro irrigation systems used in vineyards is 77% due to the same reasons that have been explained in relation with sub-tropical fruit trees. Here, we have to add the low number of emitters per plant, mainly only 1.

In the drip/micro irrigation systems employed in vegetable crops, ornamental plants and potatoes, in which in the majority of cases the number of emitters per plant is less than 1, the average global *DU* is under 70% (68%). The improvement of the global *DU* of the drip/micro irrigation systems in these crops makes necessary the employment of pressure compensating emitters (PC) and, in same cases, anti-drain emitters with low manufacturing variation coefficients.

Factors that produce non-uniformity in drip/micro irrigation systems: Between 50% (in banana plantations and fruit trees) and 70% (in vineyards) of the global non-uniformity is derived from the DU_{others} (which include plugging, emitter manufacturing variation, wear and many other factors that would cause flow rate differences among emitters even though the emitters are all at the same pressure). This factor can be corrected using good quality emitters and with a good maintenance and management of the installation, in order to avoid plugging and delay its deterioration.

Between 22% (in tomato) and 38% (in fruit trees) of the global non-uniformity is due to the $DU_{\Delta P}$ component. This factor can be corrected firstly with an adequate installation design. Furthermore, it is necessary to make a correct use of valves and pressure regulators, to frequently estimate and control the pressure in the system and/or the use of PC emitters.

The 0.6% (in vegetables), 3.4% (in tomato) and 7.4% (in banana plantations) of the global non-uniformity is derived from the DU_{dd}, produced by the unequal drip drainage, occurred during the evacuation of the pipes once the irrigation is finished, through the drips which are situated in the lowest points of the installation. The correction of this factor can be fulfilled by the replacement of those emitters with anti drainage ones, longer application irrigation and the reduction of size and slope within the irrigation sub-units.

The 2.3% (in vineyards), 4.6% (in vegetables), 6% (in fruit-trees), and 8% (in tomato and banana plantations) of the global non-uniformity is derived from the DU_{ed}, provoked by the application of unequal water depth originated in variations in plant spacing and/or emitter spacing that affect the number of emitters per unit of surface area.

These values can be compared to those obtained in the evaluations made by the Cal Poly in 260 farms in central California, in which 45% of the non-uniformity was a consequence of pressure differences, 52% was derived from other causes, 1% was due to unequal drainage and 2% was due to unequal application of water depth (BURT, 2005).

Table 4. Irrigation Uniformity

Crop		$DU_{\Delta p}$	DU_{ed}	DU_{dd}	DU_{other}	DU_{global}	**Nº Evaluations**
Banana Drip/Micro	**Average**	92,66%	98,25%	98,30%	87,78%	83,62%	**43**
	Standard desv.	7,95%	4,50%	2,43%	9,74%	11,13%	
Tomato Drip/Micro	**Average**	94,57%	98,03%	99,19%	84,10%	81,18%	**14**
	Standard desv.	5,53%	4,40%	1,30%	9,09%	7,85%	
Horticultura Drip/Micro	**Average**	88,82%	98,16%	99,76%	72,99%	68,25%	**20**
	Standard desv.	9,41%	5,68%	0,55%	20,88%	19,68%	
Vineyard Drip/Micro	**Average**	93,42%	99,37%	99,11%	80,61%	77,85%	**19**
	Standard desv.	8,45%	2,73%	2,03%	18,96%	19,20%	
Subtropical Trees Drip/Micro	**Average**	89,13%	98,33%	99,73%	84,33%	78,88%	**9**
	Standard desv.	7,95%	5,00%	0,51%	10,15%	10,10%	
Platanera Spray	**Average**	87,26	99,52%	99,06%	73,07%	69,11%	**16**
	Standard desv.	8,09	1,32%	3,75%	7,07%	7,84%	
Horticultura Sprinkle	**Average**	93,67%	100,00%	99,79%	59,71%	58,60%	**21**
	Standard desv.	6,52%	0,00%	0,91%	20,63%	20,38%	

Irrigation uniformity in spray and sprinkle irrigation systems: The average global *DU* of the spray irrigation systems in Tenerife, obtained by means of the ITRC procedure (BURT,2004) is 69% in banana plantations (butterfly type of spray) and 58% in vegetable crops (employment of a wide variety of sprays and sprinklers).

Once some modifications were considered in relation with the *DU* determined in banana plantations (fundamentally based on the use of irrigation volumes instead of flow rate, and the suppression of the aero distribution uniformity test), it was estimated that a global *DU* of 76% in spray systems in banana plantations is a value closer to reality.

The lowest global *DU* observed in the vegetable crops is a consequence of the employment (in half of the cases) of gun sprinklers with wetted diameters over 15 m and 100% overlap. These circles, combined with the desired structure of the farms occupied by vegetables, together with its small size, the wind and its disposition in terraces, are incapable of distributing water uniformly. It is estimated that in these crops, the redistribution of water once it is infiltrated in the soil plays a crucial role that balances the non-uniformity of the sprinklers.

Factors that produce non-uniformity in spray and sprinkle irrigation systems: In the spray used in banana plantations 31% of the non-uniformity is derived from pressure differences, 65.5% is a consequence of other causes (where manufacturing variation of sprays, their wear and possible plugging are included), 2.3% due to unequal drainage and 1.1% due to unequal application of water depth.

In the spray and sprinklers used in vegetables, 13.5% of the non-uniformity is derived from pressure differences, 86% due to other causes (defined in the previous paragraph) and 0.5% due to unequal drainage.

On farm irrigation efficiency

Banana plantations with drip/micro irrigation: On farm Irrigation efficiency of the drip/micro irrigation systems in banana plantations can obtain values close to 75%, a level achieved by tomato fields in the open air in agro-climate area Zone 7 (S-7).

The average on farm irrigation efficiency determined for the drip/micro irrigation systems for banana plantations is, approximately, that of 70% in the crops in the open air and 62% in greenhouse cultivation.

Greenhouse banana plantations are irrigated in a less efficient way than in the open air due to the fact that they are given a similar quantity of water, registering lower water demands. Although in several cases the GIR of the greenhouse banana plantations is relatively inferior to that in the open air, this difference cannot balance the differences of water demand between both cases.
In Zone 4 (NE-4) and Zone 7 (S-7) areas the irrigation efficiency in greenhouse cultivation is 10 and 15% inferior, respectively, compared with the efficiency in crops in the open air. In the NW-1 area it is 20% inferior. This circumstance doesn't take place, however in the SW-8 area, where the irrigation corresponds to the diverse necessities with or without greenhouses.

The lowest on farm irrigation efficiencies in banana plantations in the open air and with drip/micro irrigation take place in Zone 3 (N-3) area where the efficiency is inferior to 50%. In this area the irrigation of the banana plantations is almost the same as that in the rest of the northern area and however the average values of evapotranspiration are 20% inferior.

Tomato: The average value for on farm irrigation efficiency in tomato crops in greenhouses is higher in the SE orientated areas (Zone 6, SE-6 and Zone 7, SE-7), with an average efficiency close to 80%, than in the SW orientated areas (Zone 8, SW-8) where the average efficiency is inferior to 60%. In the SW orientated areas the irrigation is fulfilled with superior GIRs than the ones used in the SE orientated areas, although lower irrigation necessities were determined (mainly because of less wind)

The difference in efficiency between both orientated areas is due to the management factor, which in SE orientated areas reaches 95% (the GIRs are remarkably similar to the water needs) while in SW orientated areas it is inferior to 70%.

Irrigation management factor

Banana plantations with drip/micro irrigation: Irrigation management is deficient in the banana plantations in greenhouses, above all in Zone 1 (NW-1) and Zone 7 (S-7) areas, because in these areas the irrigation method is not efficient due to management factors and not for reasons of distribution uniformity.

Irrigation management is deficient in banana plantations in the open air in Zone 3 (N-3) area, in the same way. The low efficiency is due to irrigation management although, in this case there is also a problem of distribution uniformity that contributes to reduce efficiency.

Banana plantations with spray irrigation: The result of the average management of the spray irrigation systems in banana plantations is around 75%. In Zone 8 (SW-8) area there is excellent management of the spray, with an excellent result for management (93% in crops in the open air). The lack of efficiency produced in this area is derived from the limitations of the method and it can't be blamed on poor irrigation management.

In Zone 3 (N-3) area there is the worst irrigation management (44%). The lack of efficiency is due to deficient irrigation management and not to low distribution uniformity.

Tomato: The difference in efficiency between the SW and SE areas is derived from the management factor, which in the SE area reaches 95% (the GIRs adjust themselves in an extraordinary way to the water needs) while in the SW area it is inferior to 70%.

Installation maintenance factor

Banana plantations with drip/micro irrigation: Zone 3 (N-3) area has the lowest average value with reference to installation maintenance (under 80%), that is, the irrigation application uniformity is remarkably lower than what it could be. Zones 7, 1 and 2 have average values that are superior to 90%, which indicates that their systems work according to their potential characteristics. In the rest of the areas the management value varies between an average of 85% and 90%.

Banana plantations with spray irrigation: Zone (S-7) area has the lowest average maintenance value within the spray irrigation installations (79.6%). The uniformity of irrigation is 20% inferior to that which could be obtained with good maintenance of the installation. In the rest of the areas the average value for the maintenance result is superior to 90%.

Tomato: Although the average global uniformity value (DU_{global}) of the drip irrigation systems used in the tomato crop is relatively high (80% and 82% in the SW and SE areas), it is considered that, being basically PC and anti-drain emitters, they could achieve values close to 95% in the best conditions (highest value estimated in several tomato farms evaluated, in a soil-less system). Taking this value as the potential DU, the average maintenance result is approximately 85% in both crop areas.

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