EVALUATION OF IRRIGATION PERFORMANCE IN LOCALIZED IRRIGATION SYSTEMS OF SEMIARID REGIONS (CASTILLA-LA MANCHA, SPAIN)

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Keywords: drip irrigation, field evaluations, uniformity, efficiency, advisory sevice.

SUMMARY

The optimum use of irrigation water is a fundamental aspect to reach a sustainable agriculture. In this objective many factors are involved, being the irrigation water application system of irrigation water on plot one of the most important. Consequently, its evaluation has a special interest, as well as the search of feasible resolutions to problems detected within the evaluation.

In the structure of the Integral Irrigation Advisory Service (Servicio Integral de Asesoramiento al Regante, SIAR) of Castilla-La Mancha, with the principal objective of helping farmers to get a efficient and rational use of means of production, and specially water, fertilizers and energy, providing a suit scientific and technical support to optimise management, it is fundamental to broach the evaluation of irrigation system in plot.

Among the irrigation systems working in Castilla-La Mancha, the extension irrigated with localized irrigation, mainly drip, is found in a continuous and fast development. This irrigation system adjoins, in general, crops with high social interest, such as ligneous (vineyard, olive tree, almond tree, etc.) or horticultural crops (pepper, melon, etc.). In addition to this, in some cases (e.g. vineyard) crops have no irrigation tradition and they are managed by farmers who must improve their knowledge of them. This situation makes the advisory service necessary. In campaign 2000, the SIAR has realised 100 evaluations of drip irrigation installations from the entire region, embracing different productive systems (crops, management, etc). Simplified field evaluations are based on the measure of flows and pressures in 16 representative control points of the pressure distribution in the subunits. A part from the test subunits in the rest of the operational irrigation unit pressures are measured to know how the system operates as a whole. In this work are exposed the mean results obtained, projecting on detected problems and possible solution to resolve them, as well as to improve the efficiency of irrigation water application.

Among the conclusions it stands out the good uniformity that have localized irrigation installations from Castilla-La Mancha, with an average value of 82% for System Uniformity of Emission (84% Uniformity of Emission in the test-subunit). But between test areas and irrigated crops, differences appear. The main problems detected are owing to an often low working pressure. This fact is produced by different reasons, standing

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Ortega, J.F., J.M. Tarjuelo and J.A. de Juan. "Evaluation of Irrigation Performance in Localized Irrigation Systems of Semiarid Regions(Castilla-La Mancha, Spain)". Agricultural Engineering International: the Cigr Journal of Scientific Research and Development. Manuscript LW 01 007. Vol IV. 2002

out the low efficiency of pumping stations and distribution networks, lack of cleaning filters and head losses.

1. INTRODUCTION

The extension of irrigated lands has increased during the last 25 years in 75% worldwide. In Europe, this kind of lands has doubled during the same time and in Spain, they already exceed 3500000 ha. Irrigation is a strategic factor in wide areas, among which is a great part of Europe and, without any doubt, the semi-arid regions of Spain. In Castilla-La Mancha (Fig 1), Europe's third most extended region, irrigation constitutes the engine for agrarian activity. Working population in the agrarian sector is 12.3% of agrarian labour force, showing a continuous decreasing trend. On the other hand, in Castilla-La Mancha, the irrigable land is 454,633 ha (1996), which represents 10.8% of croplands (JCCM, 2000) and 12.5% of irrigated lands nationwide. Ciudad Real and Albacete are the provinces of largest irrigated area. Localized irrigation has had a rapid and important growth amid the irrigated lands, thanks to the upgrading and modernisation of certain irrigable areas and new transformations, mainly towards ligneous crops. In general, it has increased from less than 2% of irrigated area in 1980 to more than 15% nowadays.

A great share of the irrigable lands use water resources from subsoil aquifers. This constitutes a danger of over-exploitation and pollution for these aquifers, as well as a risk of desertification in some areas of Castilla-La Mancha, which are the most important risks for the sustainability of the system (Ogink-Hendricks *et al*., 1995).

Average rainfall in a standard year in Castilla-La Mancha is 435 mm, including recurrent and intense draught periods (1994, with an accumulated rainfall of 266 mm, was the driest of the past fifty years). The mean annual Potential Evapotranspiration (ETP) is higher than 900 mm, as estimated according to Thorntwaite's method, and in the districts which concentrate the largest irrigated area. These facts justify that the appropriate use of available water resources be a fundamental target for those in charge of water management as well as for the farmers. Rational and responsible management is essential in order to ensure sustainability of irrigated lands, since agriculture takes up about 80% of consumptive water use.

Factors affecting water irrigation use are multiple. Among the most important factors, are (Villalobos, 1992; Ortega *et al*., 1997; Ortega, 2000): irrigation scheduling, irrigation water supply systems, water application systems on plot, management and other. All of them must be taken into account, in a coordinate and integral way, when planning sustainable exploitation of water resources. However, water application by the irrigation system is very important, and this includes questions related to design and handling of the irrigation systems.

Within the activity developed by the SIAR in Castilla-La Mancha, whose aim is to work on assessment and training for farmers of the region, in order to contribute to a sustainable use of water resources, operation of irrigation systems is the main focus. According to this, 100 evaluations have been performed in drip irrigation systems, a relatively new system in some districts of the region; hence farmers often lack the necessary training, which is more common among traditionally non-irrigated crops (e.g., vineyard).

Simplified evaluations of irrigation systems, such as those that have been broached in this study, among the tasks developed by the Integral Irrigation Advisory Service (Servicio Integral de Asesoramiento al Regante, SIAR of Castilla-La Mancha), are an essential tool to characterize irrigation systems. In this way, it is possible to detect potential problems and supply with solutions that sort out or minimize their effects. Besides, they are necessary for a rapid and effective implementation of the SIAR (demonstrative effect) and for information feedback.

The results of the evaluations allow us to analyse operation and grade of drip irrigation systems in Castilla-La Mancha. They are a wide sample (100 evaluations), representative of the region (irrigable lands, farming systems, etc.), which enables to obtain valid conclusions about the irrigation application uniformity, a fundamental aspect of water use efficiency.

2. METHODOLOGY

The evaluations have been carried out according to Merrian and Keller's (1978) recommendations, which have been followed in later works of other authors (Keller and Bliesner, 1990; Rodrigo *et al.*, 1992, Tarjuelo, 1993; Ortega, 1999). All the field evaluations were performed in test-sites within the activity area of the SIAR during campaign 2000, whose main features are (Fig. 1):

• Irrigable lands of Hellín-Tobarra (Albacete). They are located in the Segura basin, with scarce water resources and an intermediate water application cost (subsoil and surface resources are exploited). It is a traditional irrigable area of about 12,000 ha, which began its upgrading at the beginning of the eighties by changing towards the use of drip irrigation. This system is very important at present, and farmers evince good training at its handling. Main crops are fruit trees (apricot, peach, almond trees, etc.) and horticultural crops (pepper, broccoli, artichoke, etc.), of high added value in general.

• Irrigable lands of San Clemente (Cuenca). They stand in the South of Cuenca and utilize subsoil resources, generally scarce and expensive, since they are extracted from a dynamic level of 100 m. The main irrigated crops are vegetables, as well as vineyard in the new irrigated farms. Farmers' knowledge of drip irrigation must be enhanced, especially in the case of irrigated vineyards, whose irrigation tradition is non-existent.

• Irrigable lands of Tomelloso-Alcázar de San Juan (Ciudad Real). They lay on a large irrigable area at the head of the Guadiana, where water scarcity problems are dramatic. The exploited resources come from the subsoil, i.e. aquifer 23, which has been declared over-exploited and is intimately linked to the evolution of Tablas de Daimiel. These are the major wetlands in La Mancha and have a great environmental relevance. They were declared a Biosphere Reserve by the UNESCO in 1981 and established as a RAMSAR wetland by the EU. Subsequently, several actions have been set off to regulate extractions (Extractions Plan, Income Compensation Plan, etc.), with contradictory results. Thus, water use and irrigation grade (diffuse pollution) are of a vital importance in this terrain. The main crops irrigated by drip systems, which have had a great expansion due to the scarcity of water, are horticultural (melon, pepper, etc.) and ligneous crops, such as vine.

• Irrigable lands of Vegas del Tajo (Toledo). These are traditionally irrigated farms from the banks of the Tajo river, where the modernisation process of irrigation systems that consists of changing from surface irrigation to drip irrigation is slower and has begun later than in other areas of the region (e.g., Hellín). In these lands, water resources are greatly available, and it can be stated that this is the only area within the region which has water surplus. On the other hand, since these are surface resources and the lands have been traditionally irrigated, water application costs are reduced. Main crops in the area are horticultural crops, out lighting tomato and pepper.

• Irrigable lands of El Bornova (Guadalajara). This area of Northern Castilla-La Mancha, of 2200 ha and mostly extensive herbaceous crops, is completely irrigated by sprinkling systems, chiefly solid set sprinkling systems. Therefore, in spite of being included in the SIAR activity area, there are no studies of drip irrigation in the area.

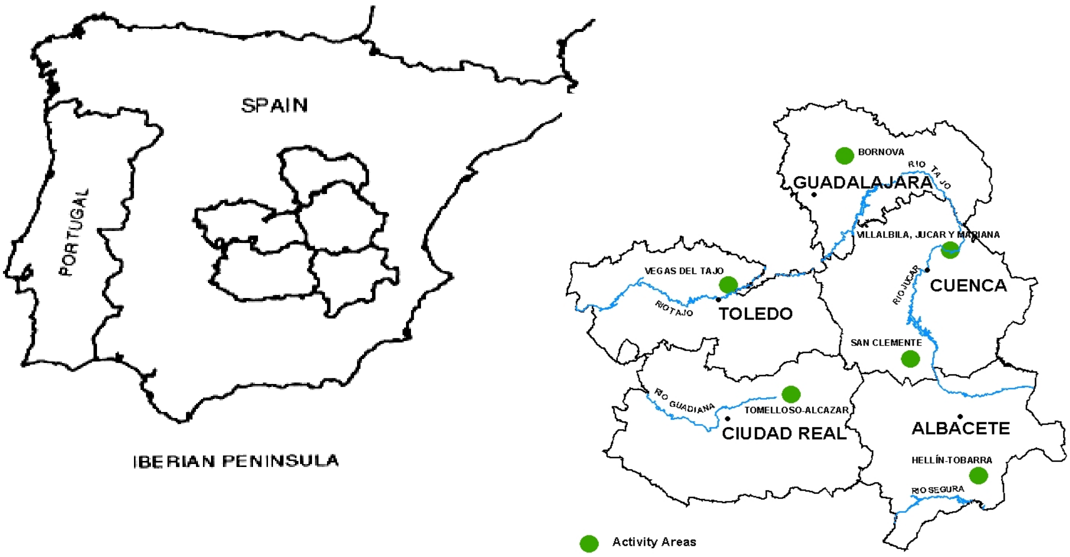

Figure 1. SIAR activity areas in Castilla-La Mancha during campaign 2000.

In order to carry out the evaluation, the first step is to choose the standard representative subunit from the studied operational irrigation unit, then determine the flow discharged by the emitters and working pressure in 16 control points (Fig. 2). For crops with wide row spacing, in the 16 control points, (Fig.2) the volumes emitted by every emitter (from 1 to 4) are measured; we work with the mean value. In crops with row spacing reduced (e.g. horticultural), two emitters are evaluated in each one of the control points. These control points ought represent the different working pressure conditions in the test-subunit. So, four laterals are taken into account in the study: those of highest pressure, lowest pressure and two of an intermediate working pressure. In each lateral, four plants are selected (control points) following a similar pressure criterion.

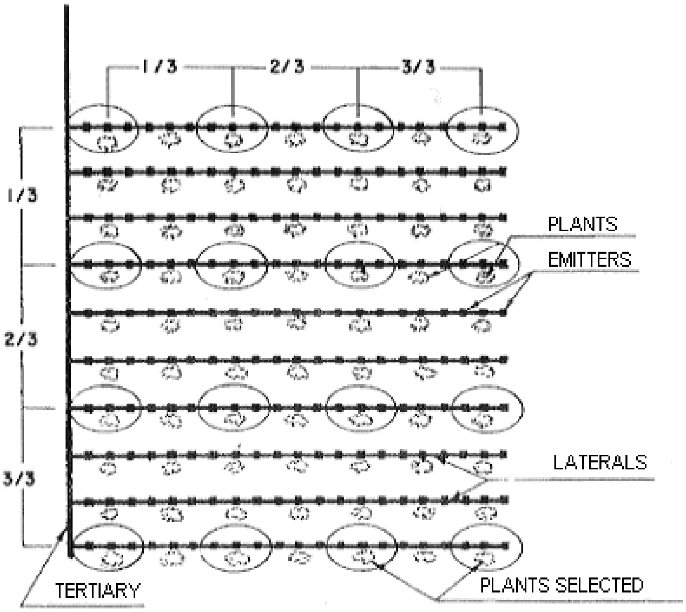

Figure 2. Diagram of the localization of control points in the test subunit.

The discharged flow in every control point is determined by measuring the volume of water discharged by every emitter during a definite time. Measuring time is usually 5 min (it varies as a function of the emitter nominal flow), so that the experimental errors committed are minimised. Pressure was measured with gauges previously calibrated by precision equipment. Using measured pressures and the discharged flows by the emitters their discharge exponent are estimated.

According to the measured data, the parameters obtained to characterize uniformity are as follows:

1. Emission Uniformity (EU). This is determined as a function of the relation between average flow emitted by the 25% of the emitters with lowest flow and the mean flow emitted by all the control emitters, such as equation (1) shows:

$$EU\ (\%) = \frac{\overline{q_{25\%}}}{q_a} * 100 \qquad (1)$$

The evaluated system is classified according to the EU values obtained, following Merrian and Keller (1978) criterion and that by the IRYDA (1983), which is more demanding, as Table 1 shows.

Table 1. System classifications according to Emission Uniformity values (EU)

EU (%)	**Classification** Merriam and Keller (1978)	**Classification** IRYDA (1983)
< 70	Poor	Unacceptable
70 – 80	Acceptable	Poor
80 – 86	Good	Acceptable
86 – 90	Good	Good
90 – 94	Excellent	Good
> 94	Excellent	Excellent

2. Absolute Uniformity Emission (EU_a). This is defined by Keller and Karmeli (1974), and it considers not only the possible effects derived from the lack of water in certain points of the plant zones, but also the excess produced as a consequence of the application heterogeneity of the system. Its expression is exposed in equation (2).

$$EU_a = 0,5 * \left(\frac{\overline{q_{25\%}}}{\overline{q_a}} + \frac{\overline{q_a}}{\overline{q_{12.5\%}}} \right) \quad (2)$$

Being: $\overline{q_{12.5\%}}$ average flow perceived by the 12.5% of plants which perceive the highest flow in the test subunit.

3. Uniformity Coefficient due to Pressure (Up). This is a measure of the potential uniformity in the subunit, as a consequence of considering only pressure variability and the kind of installed emitter, apart from the effect of other parameters (variation coefficient of emitters production, obstructions, ageing, etc.). The mathematical expression that calculates this is (equation (3)):

$$U_P = \left(\frac{\overline{P_{25\%}}}{\overline{P}} \right)^x \quad (3)$$

Being: $\overline{P_{25\%}}$ the average of 25% of the emitters with the lowest pressure (mca); $\overline{P}$ the average pressure of every control point (mca); and x the discharge exponent of the tested emitter standard curve ($q(l/h)=k \cdot P(mca)^x$).

U_p high values (higher than 90%) plus EU low values indicate that lack of uniformity problems are due to the emitters; on the other hand, U_p low values (less than 90%) plus EU low values demonstrate that the lack of uniformity may be caused either by pressure or by the emitters.

4. Flow, Pressure and Emitters Variation Coefficients (VC).

Pressure Variation Coefficient (VC_p) is determined as related to the typical deviation of pressure data and mean pressure, such as is described in equation (4).

$$VC_p = \sigma_p / \overline{p} \quad (4)$$

Flow Variation Coefficient per plant (equation (5)) is used in order to characterize water uniformity application, following the classification criterion shown in Table 2.

$$VC_q = \sigma_q / \overline{q_a} \quad (5)$$

Table 2. Localized irrigation subunits classification according to VC_q.

VC_q	Classification
> 0,4	Unacceptable
0,4 – 0,3	Low
0,3 – 0,2	Acceptable
0,2 – 0,1	Very Good
< 0,1	Excellent

The assembled interpretation of these two variation coefficients (equation (6)) is used to deepen into the origin of uniformity lack in an irrigation subunit. Thus, Flow Variation

Coefficient per Plant due to emitters (VC_e) is defined by integrating the former VC, whose expression is as equation (6) shows:

$$VC_e = \sqrt{VC_q^2 - x^2 * VC_p^2} \qquad (6)$$

Criteria followed to distinguish among the feasible causes of the lack of uniformity within the installation are as follow (Bralts and Kesner, 1983; Keller and Bliesner, 1990):

- VC_e values higher than 0.2 imply that the emitters could be the reason for the deficient uniformity, either their quality (high production VC) or the presence of obstructions.

- If VC_e value is lower than 0.2, and there is lack of uniformity ($VCq>0.3$, unacceptable, Table 2) besides, the problems are of a hydraulic origin (bad pressure regulation, inadequate hydraulic design, inadmissible pressure oscillations during irrigation period, etc.).

5. Sector Emission Uniformity (EU_s). This is determined starting from the tested subunit EU, and then correcting it by a multiplicative coefficient (f) that considers pressure distribution among the subunits that constitute the irrigation sector (equation (7)). Correction factor (f) calculations based on pressure distribution within the installation are stated in equation (8).

$$EU_s = f * EU \quad (7)$$

$$f = \left(\frac{\overline{p_{ms,25\%}}}{\overline{p_{ms}}} \right)^x \quad (8)$$

Being: $\overline{p_{ms,25\%}}$ average pressure of 25% minimum pressure values, measured at the beginning of the lateral duct and in every subunit of the operational irrigation unit (mca); $\overline{p_{ms}}$ average pressure of minimum pressure values, measured at the beginning of the lateral, in every subunit of the operational irrigation unit; and x discharge exponent from the installed emitter standard equation ($q(l/h)=k \cdot P(mca)^x$).

3. RESULTS AND DISCUSSION

In total, 100 evaluations have been carried out on localized irrigation plants during the campaign of the year 2000, all of them corresponding to drip irrigation, and spread among the different pilot zones of the activity area, except for the El Bornova sprinkling systems. The number of installations tested and the main results obtained in every pilot zone are shown in Table 3.

Average EU in the different irrigable lands of Castilla-La Mancha is 84.3%. This can be generally qualified as a high and adequate value to grant, in most cases, a correct management of the installation (e.g., irrigation scheduling) that will lead to an efficient water use. However, several important problems have been detected in the equipment evaluated: inadequate working pressures, VC of flows, pressures and emitters with a high frequency, etc. Some of these problems (e.g. working pressure or pressure differences in the subunits), do not correspond with a general decrease of the EU due to the characteristics of the emitters used in several cases; 40% of emitters can be classified as compensating (x<0.3), as shows Figure nº 3. The most common are labyrinth emitters with discharge exponent about 0.40-0.55, that represent almost the 50% of the emitters installed. IN relation with the lateral disposition, 40% are emitters integrated in the pipe, but the in-line emitters represent 30%. The rest of emitters are set in the laterals in different ways, on-line emitters are remarkable.

Table 3. Number of drip irrigation evaluations carried out in the pilot zones of SIAR action area. Average EU, EU_a and EU_s.

PILOT ZONE	EVALUATIONS	EU (%)	EU_a (%)	EU_s (%)
Hellín-Tobarra	30	87,5	86,5	86,1
San Clemente	19	84,9	87,3	82,5
Tomelloso-Alcázar	40	85,9	84,9	84,1
Vegas del Tajo	11	78,7	81,4	76,0
TOTAL/AVERAGE	**100**	**84,3**	**85,0**	**82,2**

Significant differences among the different irrigable lands can be noted (Table 3), due to many factors: irrigation tradition, user training on drip irrigation, availability and water application cost, etc. These differences constitute technical problems, which are exposed over the study. Thus, it is remarkable how maximum EU, EU_a and EU_s values are achieved in Hellín-Tobarra irrigable lands, renowned for their irrigation culture, drip irrigation tradition of the zone and owning scarce, frequently expensive, water resources. On the other hand is Vegas del Tajo, with average values 10 points lower, where farmer's training on drip irrigation handling is inferior and water availability is high. The rest of the areas show an intermediate behaviour (Table 3), highlighting Tomelloso-Alcázar de San Juan irrigable area, where water use problems are especially serious and uniformity is high, too.

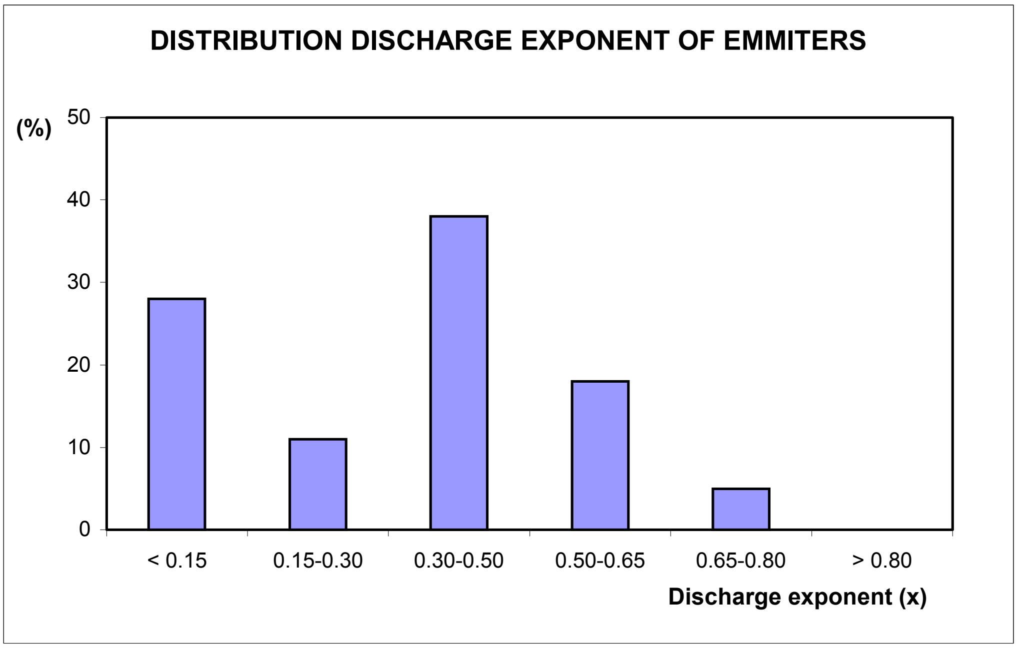

Figure 3. Discharge exponent distribution of emitters (x).

Average EU and EU_s values, as well as other parameters important for analysing irrigation subunits performance, show a variable degree of dispersion, such as Table 4 collects, the mean area of the evaluated farms being 10 ha. In the case of EU values, it is to outline a VC of 12%, also with values that range from 98% to, occasionally, values under 50%. VC high values are also noticeable in pressure variation of the evaluated subunit and calculated VC values (flow, pressure and due to emitters) (Table 4). It is important to indicate that VC associate to VC (flow, pressure, and due to emitters) are elevated (Table 4). There are large differences in evaluated subunits; however the average emitter VC is 0.1. This demonstrates an effective operation of most equipments. VCq distribution (an essential parameter to classify the behaviour of the subunits, is shown in Figure nº 4, with the uniformity criterion presented in Table nº 2. More than 50% of the tested subunits present an excellent result (VCq<0.1), but a reduce percentage (3%) present a bad result. Relating to VCe (equation 6) useful to detect where possible problems came from, present the distribution in Figure nº 5. VCe is classify in two large groups: fewer than 0.2 or higher than this one, to clarify where uniformity problems came from (VCq). Most equipments (77%) have an VCe fewer than 0.2 (Fig. 5), one presents a VCq value higher than 0.3, caused by hydraulic problems of the equipment. Rest of subunits (13%)Vce value is higher than 0.2. in this case the problem is due to emitters. The criterion to detect where problems came from is very limited when using compensating emitters. In these, an important pressure variation (e.g. hydraulic design problems in equipments), discharged similar flows are obtained (adequate VCq and EU).

Table 4. Position and dispersion measures of the 100 drip irrigation evaluations performed by the SIAR during campaign 2000.

	EU (%)	EU_a (%)	$\overline{q_a}$ (l/h)	$\overline{P}$ (mca)	P_{min} (mca)	ΔP (mca)	VCq	VCp	VCe	EU_s (%)	P_{ms} (mca)
AVERAGE	84,3	85,0	3,32	11,42	9,23	4,47	0,12	0,19	0,10	82,2	11,47
MAX	97,9	97,4	9,0	30,8	29,0	20,5	0,40	1,00	0,80	96,9	25,80
MIN	39,3	54,2	0,8	1,8	0,5	0,3	0,05	0,05	0,05	33,8	0,30
SD	10,61	9,42	1,27	5,99	6,02	3,14	0,08	0,19	0,11	10,8	5,37
VC (%)	12	11	38	52	65	70	71	97	98	13	47

EU=Emission Uniformity of the test-subunit, EU_a=Absolute Emission Uniformity; $\overline{q_a}$ =mean emitter flow; $\overline{P}$ =mean working pressure of the test-subunit, P_{min}=minimum working pressure of the test-subunit; ΔP=pressure difference in the test-subunit; VCq=Flow Variation Coefficient; VCp=Pressure Variation Coefficient; VCe=Flow Variation Coefficient due to Emitters; EU_s=System Emission Uniformity; and P_{ms}=mean working pressure in the operational unit.

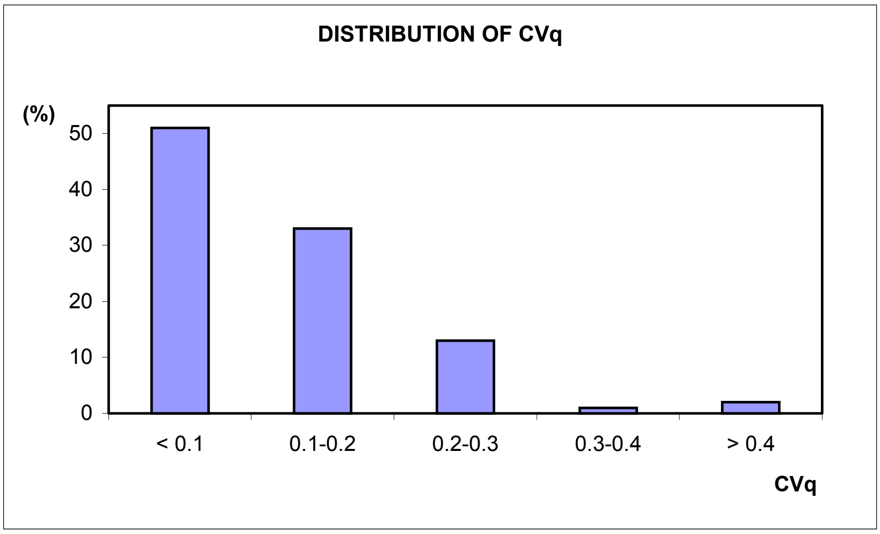

Figure 4. Coefficient variation distribution of flow (VCq) in test-subunits.

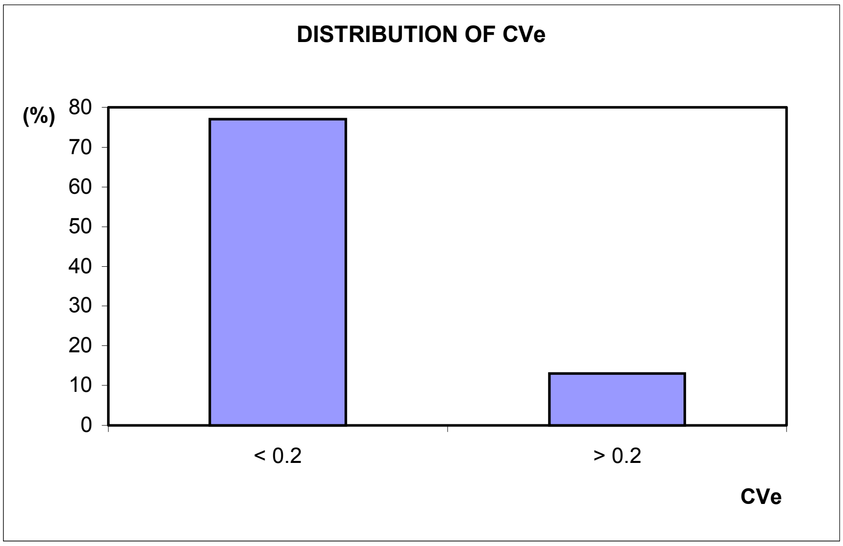

Figure 5. Coefficient variation distribution of emitters (VCq) in test-subunits.

Figure 6 collects the distribution of evaluations according to IRYDA criteria. A value of 13% represents an unacceptable EU. More than 75% of the tested subunits show EU values superior to 80%; 50% of the evaluations with uniformity values between 86% and 94% (Fig 6). If System EU (EU_S) is analysed, a similar percentage distribution can be observed in the studied evaluations. However, in general, a diminution of the values respecting to test-subunits EU is detected, as a consequence of pressure differences within the water distribution network and the subunits of the irrigation operational unit.

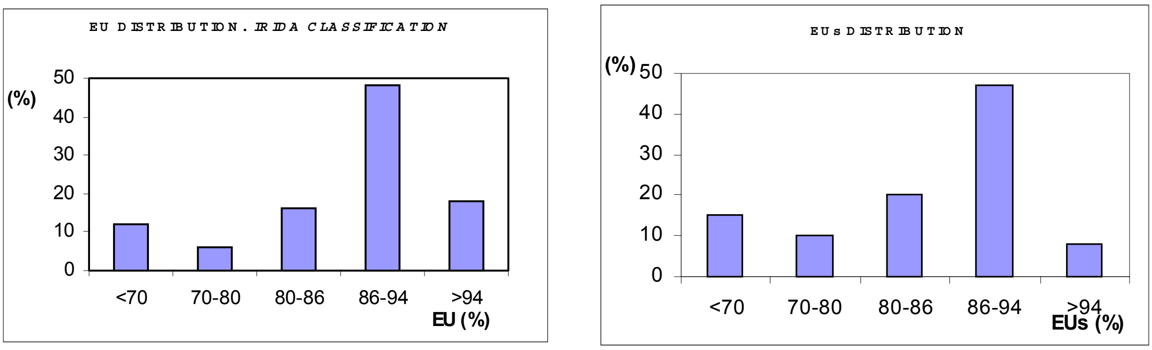

Figure 6. Frequency distribution histogram of EU and EU_s in drip irrigation system evaluations (100) carried out by the SIAR in campaign 2000

Figure 7 displays the histogram of average working pressure distribution, remarking the high number of evaluated subunits where working pressure is under 10 mca (Fig 7), which is practically 45%. Very reduced working pressures are achieved, for mean pressures just 1.8 mca and minimum pressures in the subunits of 0.5 mca (Table 4). Under these low pressure conditions, most emitters works in a very deficient way. Just some compensating emitters are able to discharge and adequate flow under these conditions, but a large number of them, will be out of their compensating range. A proportion of 35% of the installations works at an adequate pressure for most emitters (10-15 mca), being inconsequential the number of installations that register working pressures *a priori* likely to be considered as excessive (Fig. 7). Regarding pressure variations within the subunits, there are quite frequent cases when these variations are excessive (Table 4), usually due to installations design problems. However, its adequacy or inadequacy depends on the kind of emitter installed, and this is correct in many cases. In this sense, during the realization of field tests, a great amount of compensating emitters have been detected (Fig. 3), in most occasions unjustified by the plot topography. This aspect can make the installations more expensive without technical criteria for it, something relatively frequent in several Spanish irrigable areas (Ortega *et al.*, 1999; Abadía *et al.,* 2000).

Reduced working pressure values are often due to installation handling problems (pumping station regulation, cleaning status of the filters, etc.) and are, occasionally, a consequence of installation design problems. This information, together with the rest of the results and conclusions of the evaluations, has been transmitted to the farmer by SIAR technicians. The farmer has often solved the problems and deficiencies detected, thus attaining a substantial improvement of irrigation quality.

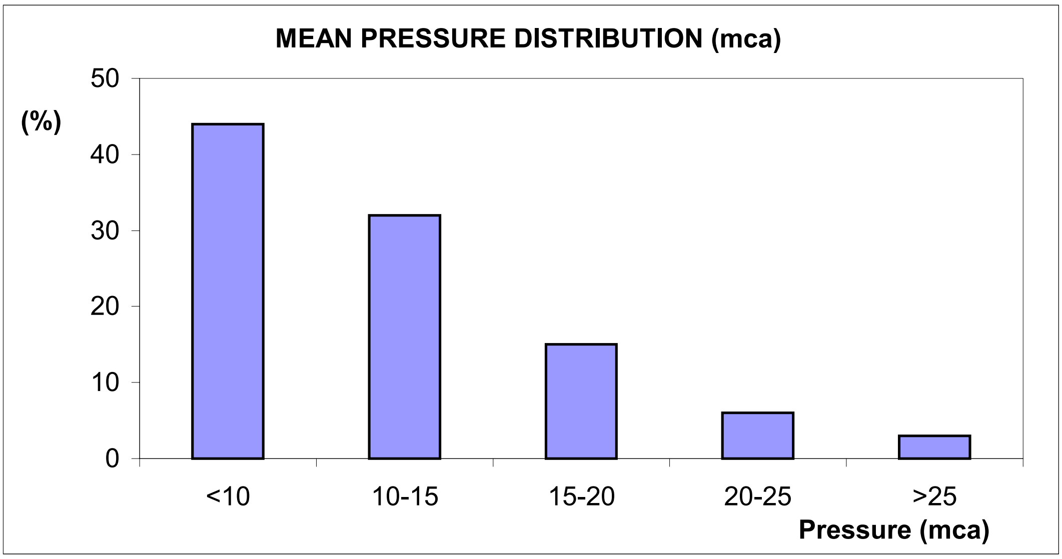

Figure 7. Average working pressure histogram of frequency distribution measured in the evaluated subunits.

An analysis of interest, which allows us to deepen into the results obtained, consists in considering the irrigated crops and the installation features in each study group.

In the case of ligneous crops, generally with high uniformity installations, two interesting cases can be broached. The apricot tree is typical in the lands of Hellín-Tobarra (Fig. 8) in the province of Albacete, with relevant drip irrigation tradition and scarce water resources. Figure 8 shows how EU is high in this case, as well as EU_s, with more than 40% subunits of excellent EU, not having found an installation with values inferior to 80% in the tested subunit (Fig. 8). In the evaluated plots cultivated with vine (30), mainly in San Clemente and Tomelloso-Alcázar areas, an important decrease of EU and EU_s is observed (Fig. 9). EU is inferior to 80% in 25% of the subunits, which indicates low-quality irrigation. However, most of 50% of the evaluated subunits obtained EU ranging from 86 to 94%, its behaviour being classified as “good” (Fig. 9). This fact can be justified, among others, according to the lack of tradition for irrigating this crop, which is widespread over Castilla-La Mancha, and it is very common in areas that have never been irrigated, where localized irrigation is a novelty. In some occasions, the uniformity problems mentioned add to irrigation management deficiencies (i.e., irrigation times and frequency), which translate into a need of improving the efficiency of water use, the action of SIAR being decisive in these cases. Other ligneous crops attain varied results depending on the irrigable zone and the farmers' irrigation experience.

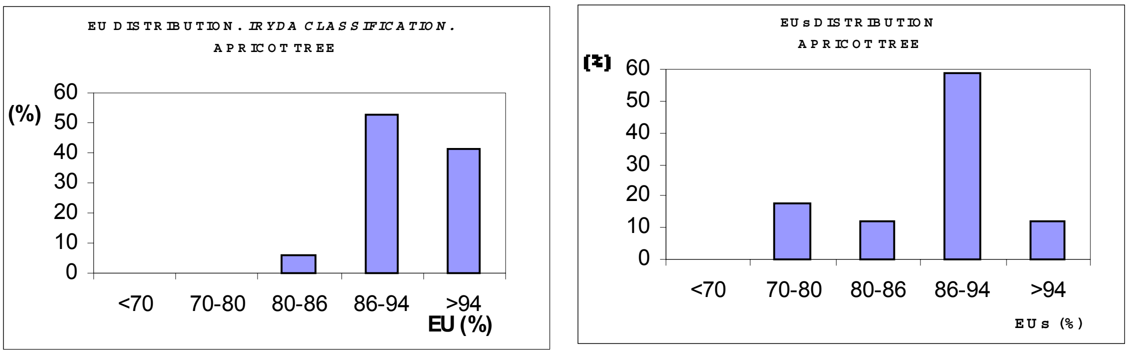

Figure 8. EU and EU_s histogram of frequencies distribution in the evaluated apricot tree installations (20) during campaign 2000.

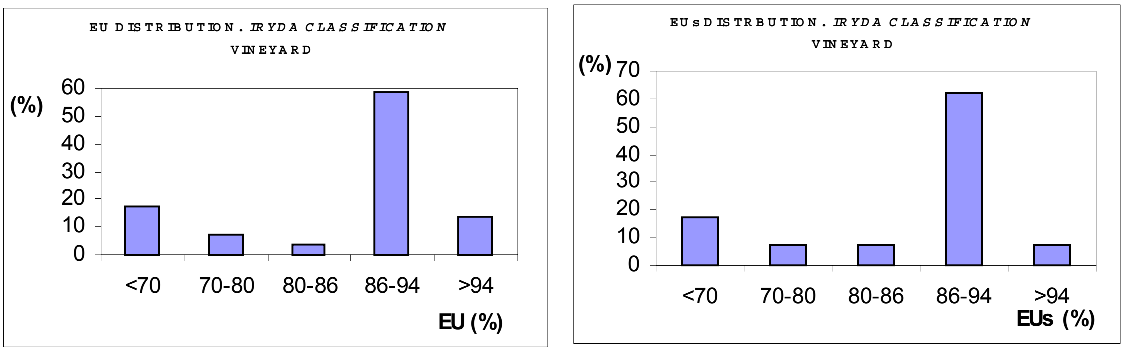

Figure 9. EU and EU_s histogram of frequencies distribution in the evaluated vineyard installations (30) during campaign 2000.

In horticultural crops, results are more evenly distributed among the different classification groups established by the IRYDA (Table 1). Nonetheless, the most frequent is still that comprised between 86 and 94% EU, and 10-20% of the installations show uniformity values inferior to 80%. Figures 10 and 11 show EU and EU_s results obtained in two crops important to Castilla-La Mancha, such as melon and pepper, correspondingly.

In the existing installations for melon, mainly located on Tomelloso-Alcázar irrigable lands, mean EU is beyond 80%, although there are 18% with inferior to 80% mean EU, 12% being classified as of excellent uniformity (Fig. 10).

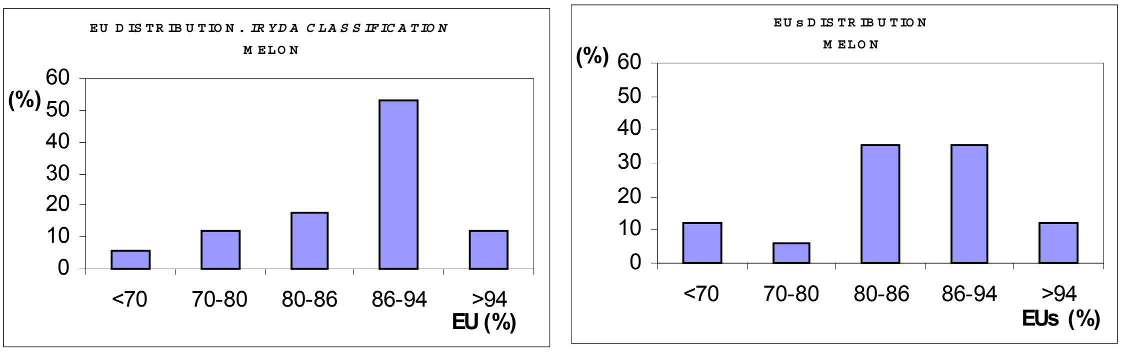

Figure 10. EU and EU_s histogram of frequencies distribution of the melon irrigation installations evaluated (18) in campaign 2000.

In Figure 11, where the results of pepper plots evaluated are collected, average uniformity is higher than in the case of melon. This is usually due to the great horticultural tradition of these farmers, who often perform a better handling and maintenance of the installation (filters head, emitters cleaning program, etc.).

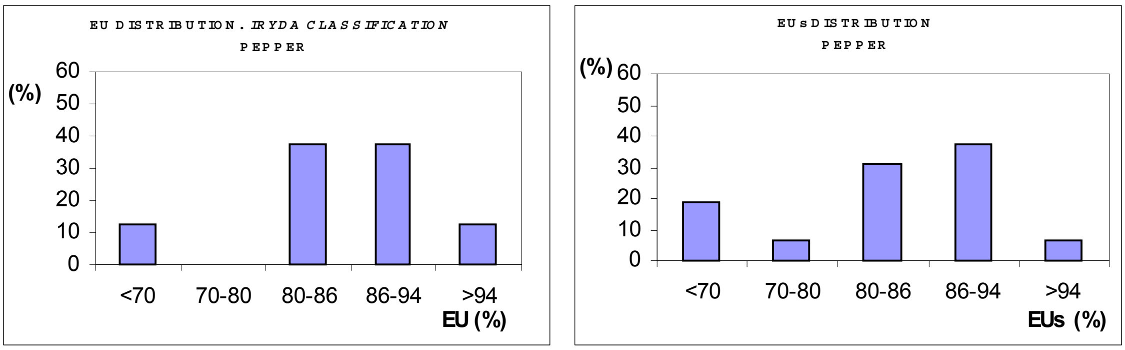

Figure 11. EU and EU_s histogram of distribution frequencies from irrigated pepper plots evaluated (18) during campaign 2000.

Generally, results are similar to those that can be found in other Spanish irrigable areas (Castell, 1985; Ortega *et al*., 1999; Abadía *et al.,* 2000), although average uniformity values are higher, likely due to the quality of installations (materials and design) and to good handling, as a consequence of having more accumulated experience than in other evaluated areas. On the other hand, in traditionally irrigated lands, such as those studied by Castell (1985), Ortega *et al.* (1999) and Abadía *et al.* (2000), the change of irrigation system takes more time to be implemented into their culture. However, when farmers get accustomed to the handling of new irrigation techniques, results are very good, such as is the case of Hellín-Tobarra irrigable lands. Therefore, after a general modernization action in the irrigation systems that implies great changes (irrigation systems, automation, etc.), it is crucial to dispose of assessment services which can help the farmer with the management and train him to obtain the best results from the available installations.

4. CONCLUSIONS

The most remarkable conclusions of this work are:

- Average Uniformity of Emission, Absolute average Uniformity of Emission and System average Uniformity of Emission are generally high; drip irrigation systems in Castilla-La Mancha do not limit the high water use efficiency when being adequately handled.
- The most important problems detected are caused by low working pressure and, occasionally, by an excessive variation of pressure within the subunit. These aspects ought to be controlled by a proper regulation of the installations, automated when possible, and an adequate design.
- There is a strong trend towards the installation of compensating emitters, in some cases without sufficient technical or economic reasons.
- The areas with more water scarcity and where the crops of highest profitability are grown, usually linked to an old irrigation tradition, with early installations of drip irrigation, show higher uniformity values in tested subunits (EU) as well as in the systems (EUs).
- The activity of the Integral Irrigation Advisory Service (Servicio Integral de Asesoramiento al Regante, SIAR) is fundamental in order to improve irrigation quality and water use efficiency, this need being especially evident in some innovative crops, such as is the case of the vineyard. Thus, farmers' commitment through the irrigation union groups, which make them take part, is crucial for the service.

GLOSSARY OF SYMBOLS

EU: Emission Uniformity (%).

EU_a: Absolute Uniformity Emission (%).

EU_s: Sector Emission Uniformity (%).

f: Correction factor to caculated EU_s.

P: Presión de trabajo del emisor (mca).

$\overline{P}$: Average pressure of every control point (mca).

$\overline{P_{25\%}}$: Average of 25% of the emitters with the lowest pressure (mca).

P_{min}: minimum working pressure of the test-subunit (mca).

$\overline{p_{ms,25\%}}$: Average pressure of 25% minimum pressure values, measured at the beginning of the lateral duct and in every subunit of the operational irrigation unit (mca).

$\overline{p_{ms}}$: Average pressure of minimum pressure values, measured at the beginning of the lateral, in every subunit of the operational irrigation unit (mca).

$\overline{q_a}$: Average flow emitted by all the control emitters (l/h).

$\overline{q_{12.5\%}}$: Average flow perceived by the 12.5% of plants which perceive the highest flow in the test subunit (l/h).

$\overline{q_{25\%}}$: Average flow emitted by the 25% of the emitters with lowest flow (l/h).

Up: Uniformity Coefficient due to Pressure (%).

VC: Coefficient Variation (%).

VC_p: Pressure Variation Coefficient (%).

VC_q: Flow Variation Coefficient (%).

VC_e: Coefficient per Plant due to Emitters (%).

x: Discharge exponent of the tested emitter standard curve.

σ_p: Typical deviation of pressure data.

σ_q: Typical deviation of flow data.

ΔP: Pressure difference in the test-subunit (mca).

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ACKNOWLEDGMENTS

These works have been carried out within the Collaboration Convention between the Regional Department of Agriculture and Environment and the University of Castilla-La Mancha for the implementation of an Integral Irrigation Advisory Service (Servicio Integral de Asesoramiento al Regante, SIAR). The authors wish to thank the General Direction of Rural Development for financial support of the SIAR, as well as the farmers of Castilla-La Mancha, who are really involved with these activities, for their cooperation.