IRRIGATION EFFICIENCY AS A PERFORMANCE PARAMETER
IN THE COMMAND AREA OF THE MIDDLE AND LOWER TUNUYÁN RIVER
MENDOZA, ARGENTINA

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INTRODUCTION

The Province of Mendoza (Argentina) comprises the largest area under irrigation in the country (360,000 hectares), with the exception of areas under supplementary and/or complementary irrigation. Due to its desertic [desert-type ? desert-like ?] climate and a practically non-existent mean annual precipitation (180 mm), agriculture in its oases depends solely on the water of its five snow-fed [snowmelt-fed ?] mountain rivers. The capital city of Mendoza is built on the Mendoza River, with an urban population of over 500,000 inhabitants. The Middle and Lower Tunuyán River command area has become an important agricultural center, with its own cities and industrial and services infrastructure. Both these rivers and their command areas constitute what is known as the northern oasis; the Diamante and Atuel rivers, in the southern part of the province, form the other two (Fig. 1). An important and increasingly exploited aquifer feeds a large number of wells, the so-called "sixth river".

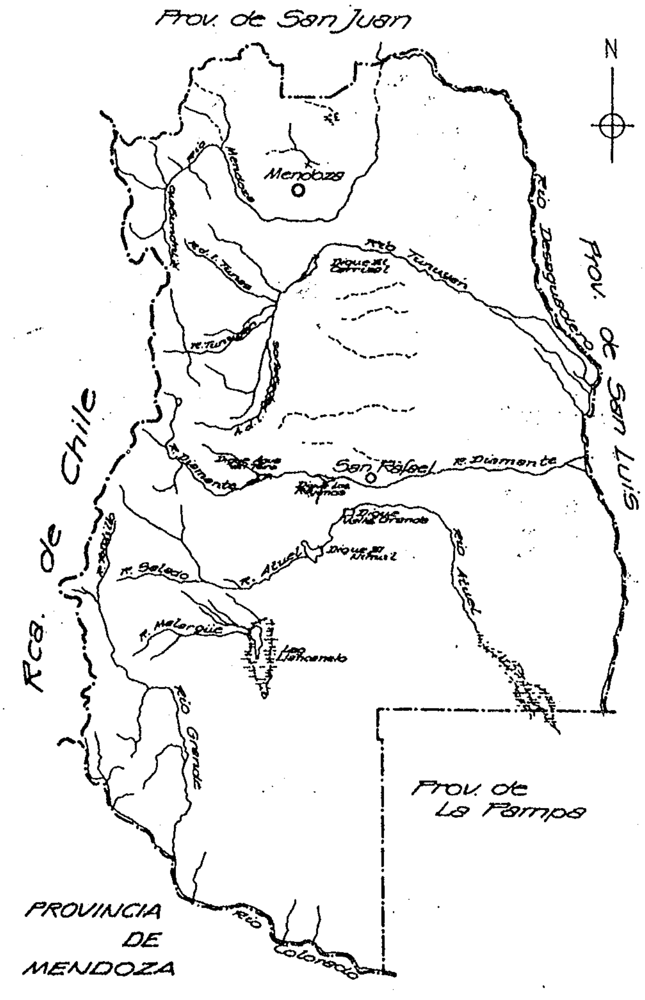


Figure 1. Irrigated oases in the Province of Mendoza

Surface irrigation, with furrows or borders (100 m long) and with neither slope nor runoff, prevails. Vineyards (espalier system), fruit and olive trees, and vegetables are irrigated by means of furrows of variable width (0.50-0.80 m for the former and 0.20-0.50 for the vegetables). When fully grown, vineyards (trellis system) and seed and stone fruits are irrigated by means of borders, the width of which ranges from 6-7 m to 15-20 m.

Irrigation water distribution is done mostly with fixed and/or mobile proportional dividers, and either metal or wooden gates. Water delivery, even nowadays, is based on the Inspector's and the gatekeepers' experience and is done according to the number of hectares registered with definitive and/or eventual irrigation rights.

At the provincial level, water is administered by the General Department of Irrigation (DGI), an autonomous and autarchic agency responsible for water policy and water police, in addition to managing and maintaining dams and main canals. The extensive irrigation network (Fig. 2), which criss-crosses several cities, is mostly earthen and usually accompanied with runs parallel to an open wastewater collector network, the maintenance of which is irregular and becomes more intensive in water-rich years.

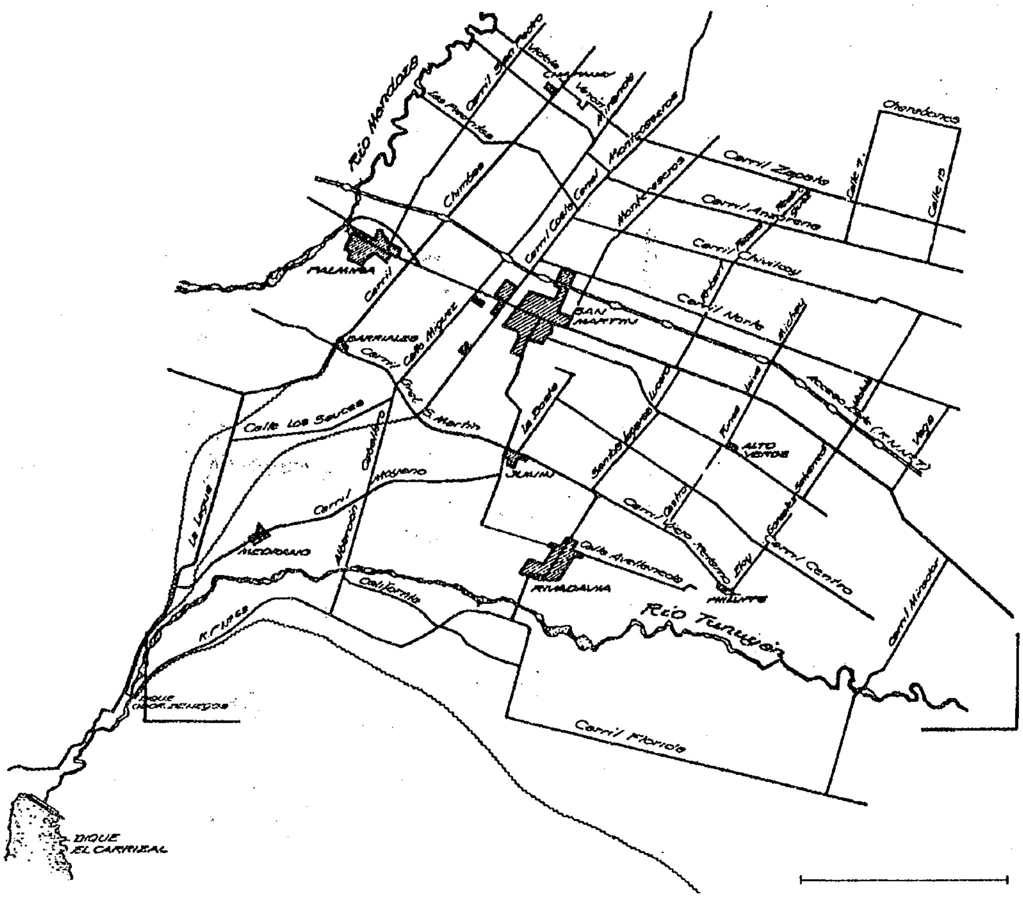


Figure 2. The Middle Tunuyán River's irrigation network

There are Users' Organizations --known in Mendoza as Canal Inspections-- at different levels (consolidated Inspections, associations, and federations). They are responsible for managing irrigation water at the secondary and tertiary canal level while farmers, in turn, are responsible for cleaning the tertiary and quaternary canals. This unique organizational structure has attracted the attention of the International Irrigation Management Institute (IIMI), as manifested in its Research Program on Irrigation Performance (RPIP), carried out with the cooperation of ILRI (Wageningen) and INA (formerly, INCYTH) in Mendoza, Argentina.

The area under study corresponds to the "Montecaseros" Consolidated Inspection (Fig. 3), which is irrigated by the secondary canal of the same name, derived from the San Martín main canal, and by 13 tertiary canals ("hijuelas"). For this research project the Chivilcoy tertiary canal's command area was selected as it is representative of the different irrigation methods used in the province.

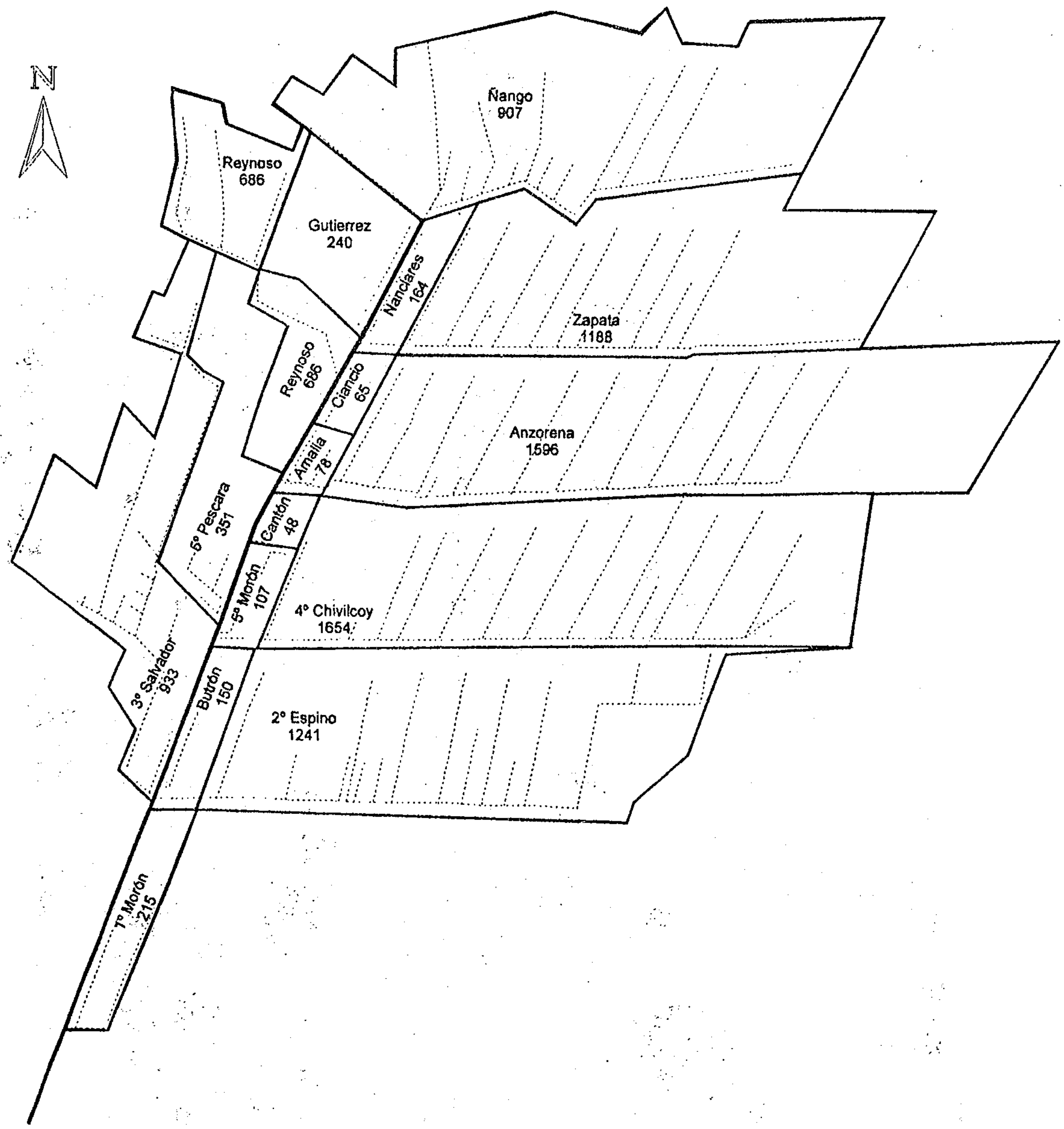


Figure 3. The "Montecaseros" Users' Organization

The predominant crop is grapes of the so-called "common" varieties, produced either for the table or for wine-making for the domestic market. The trellis system is commonly used, and farming plots are divided in blocks 80 to 120 m long, with no slope in the direction of irrigation in order to compensate for the natural west-east slope. As a rule, crops are irrigated by means of broad furrows with no runoff, which become borders in times of greater crop water requirements. This form of crop irrigation together with plot size, farmer characteristics, quality and frequency of labor, average yields, etc. serve to typify the region.

In recent times there has been a dramatic increase in the area farmed with stone fruit trees, especially plum trees, which have thus become the second most important crop. Fruit trees and vineyards (trellis) are furrow-irrigated during their first years; later on the broad furrows become borders. The length of the irrigation units is very similar to those of vineyards, a traditional characteristic is difficult to change. However, the ever-growing availability of farming machinery is gradually making the younger generation of farmers adopt a new criterion.

Figure 4. Furrow-irrigated vegetables in the study area.

Vegetables represent a small percentage of the farmed area (Fig. 4). Tomatoes for the canning industry are the prevailing crop, which --due to the mostly loose soils in the area-- produce good yields. Irrigation efficiency figures, however, are low. In general, farmers ignore the soil depth to be wetted each time and apply water depths that are more suitable to the needs of deep-rooted permanent crops, such as vineyards and fruit trees. As a result, they induce considerable percolation, rising phreatic levels, and inefficiencies.

The average farm size in the study area is 10 hectares (ha), the most important strata being 0-10 ha and 10-25 ha (1988 Agricultural Census).

Most of the owners (80%) no longer live on the property, as they used to do in the first half of the century, but in neighboring towns --Montecaseros and San Martín-- and in central urban areas (the capital city, Guaymallén, Godoy Cruz) or in the city of Junín, east of the oasis. The owner's distance from his property and from the person in charge of its farming and irrigation leads to administrative problems for the Users' Organization, to which the Water Law assigns full responsibility for water management.

MATERIALS AND METHODS

Coordination of the external water network management (turnout) and crop water requirements, together with the training of users, are of the utmost importance for an efficient water use. These elements --rational network management and the adequate training of users-- form the basis for sustainable water use in Mendoza's oases.

The evaluation methodology used was developed by the Department of Irrigation and Drainage of the INA's Andean Regional Center (CRA) (Chambouleyron and Morábito, 1982). It has been designed according to field conditions representative of the irrigation practices of farmers in Mendoza: surface irrigation, furrow or border, with neither slope nor runoff, and perfectly suited to very short administrative times. These conditions, in turn, result in the need to manage large instant flows at plot level.

This methodology focuses on the integrated analysis of water use on the farm from its intake. This approach also affords the possibility of measuring conveyance efficiencies and losses along the irrigation network, from the farm's intake to the diversion itself (Fig. 5).

The methodology makes use of a field survey form. On it, physical data (location, area with irrigation rights, cropped area, area effectively irrigated, etc.) are recorded. Data on surface and underground irrigation water are also collected (flow gauging, turnout, duration of turnout, area effectively irrigated per turnout, conjunctive use --or not--, well flow, pumping equipment efficiency, pump fuel/energy consumption, age of the well, static and dynamic well levels, length of time the pump is in operation, number of irrigations per growing cycle, etc.).

In addition to the above, the survey form includes items on all data that contribute to a description of the crop/s, block by block (area, training system, age, variety, irrigation method, general condition of the crop, fertilizers, mechanization, irrigation infrastructure, yields, farmer's technical know-how, etc.).

The field survey concludes with a detailed description of the irrigation method applied (border or furrow) and with the calculation of physical parameters. The following parameters are measured:

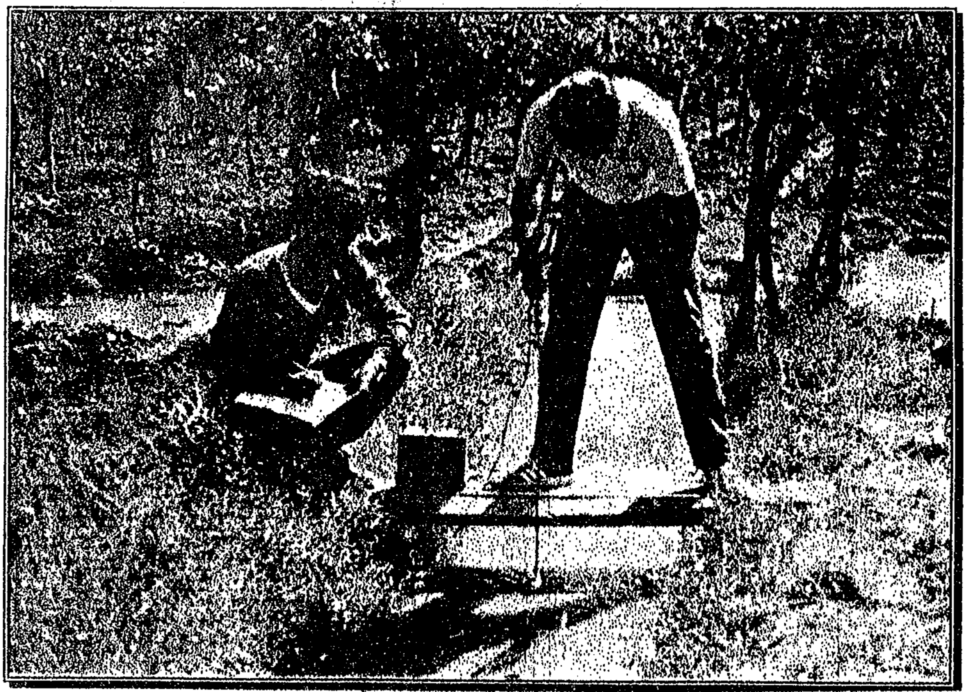


Figure 5. Measuring flows on a farm.

irrigation unit slope, furrow/border length, furrrow/border width, number of furrows/borders irrigated at the same time, area of and flow applied to the irrigation unit, application times, and water front advance and recession times. Also measured are water infiltration velocity (double-ring infiltrometer), and soil moisture content at the time of irrigation in order to relate it to soil texture (Fig. 6) and storage capacity. Thus, it is possible to calculate the irrigation depth that should have been applied when irrigating.

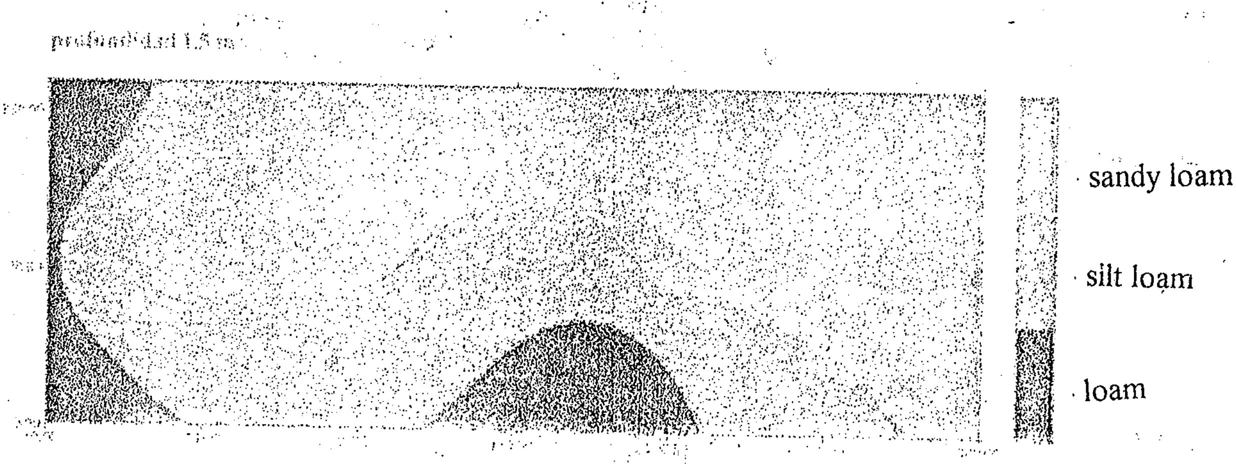


Figure 6. Example of soil texture distribution

With the field data conveniently systematized and processed with models, such as ERFIN and DISEVAL --developed at the Andean Regional Center in Mendoza--, it is possible to calculate the various efficiencies in order to characterize and rank irrigation efficiency at farm level.

The methodology herein described had to be adapted to ICID's instructions and definitions (Bos et Nugteren, 1990), the more common of which are included below. Wherever necessary, ICID acronyms are given between parentheses and next to those corresponding to the local methodology.

Conveyance efficiency (ec). It is the efficiency of canal and conduit networks from the reservoir, river diversion, or pumping station to the offtakes of the distributary system.

Distribution efficiency (ed). It is the efficiency of the water distribution canals and conduits supplying water from the conveyance network to individual fields.

Field application efficiency (ea). It is the relation between the quantity of water furnished at the field inlet and the quantity of water needed and made available for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle.

Overall or project efficiency (ep). It represents the efficiency of the entire operation between river diversion or other source of water and the root zone of the crops.

Tertiary unit efficiency (eu). It is the combined efficiency of the water distribution system and of the water application process.

Irrigation system efficiency (es). It is the combined efficiency of the systems of water conveyance and distribution (this is not an ICID standard term).

As our methodology places special emphasis on the irrigation unit, it is deemed convenient to define the efficiencies resulting from its use.

Application efficiency (EAP). It is the ratio between the water depth stored in the root zone and the water depth derived from the farm inlet.

Storage efficiency (EAL = ES). It is the ratio between the water depth stored in the profile after irrigation and the water depth stored in the profile before irrigation.

Plot distribution efficiency (EDP). It is the ratio between the minimum infiltrated depth and the mean infiltrated depth.

Internal conveyance efficiency (ECI). It is the ratio between the water depth entering the plot and the water depth derived from the farm inlet.

Internal use efficiency (EUI). It is the ratio between the water stored in the root zone and the volume conveyed to the farm.

$$(EUI = EAP \times ECI)$$

Another way of expressing it is:

Farm irrigation efficiency (ERI). It is the irrigation efficiency at the farm level.

(ERI = EAP x ECI).

RESULTS

Regional

PLOT*		AREA*	
Efficiency	%**	Efficiency.	%
ea	67	ec	74
EDP	83	eu	55
ES	61	ep	41

* Ref: * Level of parameter's determination

** Average Value.

Unlike the Mendoza River, the Lower Tunuyán is completely regulated by means of a storage dam (El Carrizal) and a diversion dam (Tiburcio Benegas).

The methodology followed involved gauging the entire irrigation network at a specified time, beginning at tertiary canal level and measuring flow at the farm inlet. The evaluation of conveyance and/or administrative losses is followed by the gauging of secondary and primary canals all the way to the diversion dam (offtakes).

At farm level, and always considering the 80,000 ha of the command area of the Lower Tunuyán River, the Department of Irrigation and Drainage Engineering of the Andean Regional Center of INA (formerly INCYTH) carried out field studies, measurements and evaluations which made it possible to assess irrigation efficiency for each of the prevailing crops in the study area (Chambouleyron et al., 1985).

The values presented in Table 1 show that:

At farm level, the farmers of the command area of the Middle and Lower Tunuyán River irrigate with such low storage efficiencies (if we assume that ES = 80-90% is acceptable for the irrigation method used and for the conditions of the area), that it can be considered as a sub-irrigation. With the inflexibility of the rotation system, a plot is irrigated once every thirty or more days.

The application efficiency of the different irrigations throughout the agricultural crop cycle (ae = 67%) renders, just like storage efficiency, a relatively low value. This is due to the farmers' lack of knowledge of "when" and "how much" to irrigate. Contrary to what happens with storage efficiency, these values could be significantly increased by making a few changes in the area of the irrigation unit and in the water application times.

Distribution efficiency values (DE = 83%) show that the property is adequately systematized and that farmers have experience in irrigated agriculture. In order to increase these values, farmers should only slightly modify the levelling of the irrigation unit at the end of each agricultural cycle, systematize distribution in order to prevent erosion at the head, irrigate without runoff or replace traditional plowing with chemical plowing practices.

At the irrigation system level, both efficiency values in the tertiary canal (ue = 55%) and conveyance efficiency values from the primary canal to the farm's intake (ce = 74%) show great flow losses (deep percolation, canal and/or gate breakage, overflows, obstruction of flow dividers, etc). Though part of this water can be recovered by capillary rise, the damages that water table rises cause on the crops and on the soil, the contribution of salts and the productive deterioration of the area cannot be ignored.

Project efficiency values (pe = 41%) include the failures of the system as well as the expansion

restrictions in the productive area and precludes the possibility of incorporating the irrigated oasis into the increasing demand brought about by the foreign market and the Mercosur.

An evaluation of the electromechanical efficiency of the pumping equipment in the area rendered an average value close to 30% due to aging, obsolescence, over-dimensioning, lack of adequate maintenance and deficient operational management of most wells in the area. This low value points to a significant misuse of groundwater and electricity with the ensuing negative consequences on crops' yields.

Since the irrigation method depends on the farmer, his tradition and knowledge of soils and crops, the efficiency values obtained in the command area of the lower Tunuyán river are representative of the agriculture that prevails in the oasis.

Soil texture in the area is homogeneously distributed (deep loose soils, sandy to sandy-loam texture, without water table or profile salinization problems).

The prevailing crops are vineyards (trellis and espalier), stone fruits, olives, horticultural crops (garlic, onion and tomato), and vegetables.

The average field-measured efficiency values, expressed according to crop type (deep, intermediate and superficial root) and irrigation method (furrow, border without slope and runoff) are:

Table 2. Efficiency values in vineyards (%)

Sistema de conducción	ESPALDERO				PARRAL			
Métodos de riego	EAP (ea)	EDP	ECI	ERI	EAP	EDP	ECI	ERI
Surcos	63	91	96	60	59	86	93	57
Melgas	61	96	89	54	54	93	93	51
Surcos y melgas	63	92	95	58	56	89	93	54

Ref: EAP : application efficiency
EDP: plot distribution efficiency
ECI: internal convenyance efficiency
ERI: farm irrigation efficiency (ERI = EAP x ECI)

Table 3. Efficiency values in stone fruits (%)

METODO RIEGO	EFICIENCIAS			
	EAP	EDP	ECI	ERI
SURCOS	83	83	90	73
MELGAS	60	95	87	52
SURC.Y MEL	70	90	88	61

Table 4. Efficiency values of alfalfa and poplars (%)

METODO RIEGO	EFICIENCIAS			
	EAP	EDP	ECI	ERI
SURCOS	68	83	93	61
MELGAS	56	84	92	52
SUR-MEL	67	83	93	62

Table 5. Efficiency values in horticultural crops (%)

METODO RIEGO	EFICIENCIAS			
	EAP	EDP	ECI	ERI
AJO	35	94	90	31
CEBOLLA	32	91	90	28
TOMATE	50	82	92	45
PROMEDIO	39	89	91	35

As can be observed in tables 2 to 5, efficiency values at farm level clearly show that deep rooted crops are the most efficient. Fruit trees, alfalfa and poplars yield average values close to 60%. Vineyards, an intermediate root crop, yields an average value of 56%, while horticultural crops show very low efficiency values (35%).

Low field-measured efficiency values in shallow root crops are due to similar flows, rotation systems and application times for deep rooted crops, such as vineyards. The natural characteristic of crops with a rather shallow root system calls for the need of a frequent irrigation regime, with small water depths (no more than 50-60 mm) in each irrigation. These water depths are difficult to apply with surface irrigation if there is not a perfect irrigation unit levelling (furrow or border).

Of course, the prevailance of the viticultural and fruit model has given rise to a management system which extends to the rest of the crops without taking into account their specific requirements. Farmers are used to manage a certain flow for a certain number of irrigation units (a number of furrows or borders that are simultaneously irrigated in one or more irrigation fronts). In practice, the water depths are close to 100 mm in each irrigation.

This value, which is almost twice as much the requirements of crops such as garlic, onion or tomato, renders very low application efficiencies. As regards horticultural crops, which require a greater irrigation frequency (which is not achieved with the current rigid rotation system of surface distribution), in most cases groundwater must be used. Finally, it should be pointed out that together with the low efficiency of shallow root crops there is the inefficiency of the pumping equipment.

Tertiary canal level ("hijuela")

Table 6 shows the field-measured efficiency values in the Montecaseros secondary canal (Department of San Martín). They correspond to 14 evaluations carried out in farms that are irrigated with water drawn from tertiary canals ("hijuelas"), on which the respective intakes are located.

Efficiency values at Users' Organizations level (Consolidated Montecaseros Inspection) are compared to the values measured for the whole Middle and Lower Tunuyán river command area (159 evaluations). This is achieved in view of the similarity that exists in the tilling and irrigation practices and in the

Table 6. Efficiencies measured in different crops (%) (Montecaseros Canal, Department of San Martín,

CULTIVO	EFICIENCIAS				
1. VID	ES	EAP	EDP	ECI	ERI
PARRAL	100	35	87	100	35
	100	54	96	100	54
	100	47	97	100	47
	100	26	99	100	26
	78	-	-	-	-
	100	15	99	64	10
ESPALDERO	84	98	98	82	80
	46	-	-	-	-
PROMEDIO	88	46	96	91	42
2.FRUTALES	100	51	100	85	43
	59	-	-	-	-
	44	-	-	-	-
	89	100	100	90	90
	42	-	-	-	-
	91	100	100	97	97
PROMEDIO	71	84	100	91	77
PROM.GRAL	81	58	97	91	53

As a result of this comparative analysis, the following should be pointed out:

Distribution and conveyance efficiencies at tertiary canal level show acceptable similar values (90-95%) to those obtained at Tunuyán river command area and the relative soil homogeneity in the area.

In the case of vineyards, application efficiency values are quite lower than the values measured in the area. The average value obtained in the Montecaseros Inspection is 46%, while the average for the whole area is 59%.

On the other hand, the average values for stone fruits (peaches) in the Inspection is 84%, while in the whole area it is 70%.

As has already been pointed out, application efficiency is a useful parameter that helps to know the exact amount of water that the crop has used. Low EAP values show that farmers do not know how to choose an adequate irrigation opportunity according to soil, climate and crop characteristics and how much water to apply in each irrigation throughout the whole cycle.

However, low efficiencies at farm level are affected by a parameter which is external to the farmer's management: the administrative management of the system (in this case, performed by the Users' Organization, the consolidated Montecaseros Inspection). In fact, the practice is to convey, every 13 days, very high flows (4-5m3/s) in very short periods (10-12 minutes) per ha. This type of conveyance affects smaller properties with only one intake. Farmers must prepare the farm so as to receive in one or more irrigation fronts all the flow and manage it in such a way as to minimize conveyance losses in the internal network of ditches and canals and efficiently apply it to the irrigation unit in such a short time.

As larger properties, on the other hand, have more than one intake, the farmer can make a more rational management since he must not pay so much attention to the systematization of his farm in order to obtain the same results.

SIZE OF THE PROPERTY AND EFFICIENCY

In order to corroborate an assumption directly related to irrigation efficiency and property size, these two variables were correlated (Table 7) taking into account the irrigated area (this information was obtained from "in situ" surveys was carried among the administrators of the UO's of the Middle and Lower Tunuyán river).

The results show that there is a marked difference between properties larger than 10 ha and smaller properties. In Figure 7, it can be seen that the application efficiency parameter tends to increase with the size of the property, reaching a value close to 52% in properties larger than 10ha.

Table 7. Application efficiency values for different strata of irrigated area

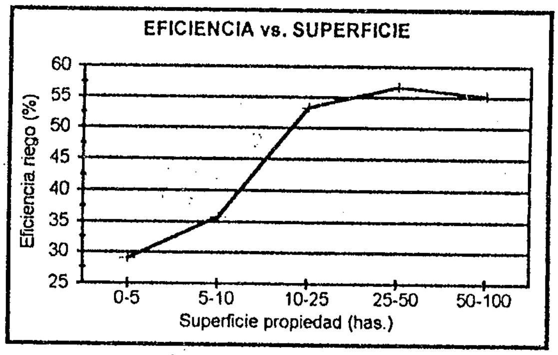
SUP.PROP. (ha) (.)	(%)	EAP (ea)		LIMITE	
		(X)	(S)	SUP.	INF.
0 - 5	26.4	29.0	3.5	22	36
5 - 10	15.1	35.8	4.6	27	45
10 - 25	23.9	53.3	3.6	46	60
25 - 50	16.4	56.7	4.4	48	65
50 -100	18.2	55.2	4.1	47	63

Ref: (X) mean

(S) standard deviation

(.) From Users' Participation (Chapter III) Bustos, R. et al., Mendoza, April 1995

Figure 7. EAP values per stratum of irrigated area



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Low EAP values point to the fact that small farmers, with a few exceptions, lack adequate technical knowledge.

DISCUSSION OF RESULTS AND CONCLUSIONS

At regional level:

The results so far obtained show that there is a clear need to make urgent improvements in the water distribution scheme throughout the long irrigation network. Such improvements include changes in the current rigid irrigation rotation systems and reductions in the flows derived from each rotation system so as to adapt frequencies and delivery times to real crop evapotranspiration demands.

It is well known that the inhabitants of the irrigated oasis of Mendoza are very much concerned about soil and water pollution. Thus, through irrigation efficiency it is possible to determine saline soil pollution and its negative consequences, not only at individual farm level but also on the whole irrigation system.

From the strictly agricultural point of view, large percolated volumes give rise to areas with water table (water-logged areas), which are restrictive to crop growth and development in the region. Generally, these point pollution sources have been gradually expanding and have generated a desertification process which has been difficult to overcome.

The implementation of regional studies will make it possible to improve and optimize water management.

At Montecaseros Inspection level:

When comparing the average values in the Lower Tunuyán area - according to crop types - the Montecaseros Inspection yields distribution and conveyance efficiency values which are similar and acceptable (90-95), though application efficiency values are quite lower than the average in the area.

In the case of vineyards, the average EAP value at the Montecaseros Inspection is 46% while the average for the whole area of the Lower Tunuyán river is 59%. As for stone fruits, mainly peaches, the Montecaseros Inspection yields average values of 58% while the area's total is 70%.

As has already been stated, the EAP is a useful parameter to know the exact amount of water used by the crop. Low application efficiency values indicate a lack of knowledge of the opportunity and amount of water to apply in each irrigation. This concept is closely related to the identification of soil textures on which crops grow, to the soil depth explored by roots and to the specific evapotranspiration rate of each crop.

Farmers should understand the interrelation dynamics of all factors that participate in irrigation: crop, soil, climate, rotation system, etc. in order to be able to irrigate only when it is needed, to replenish the water used by the crops according to evapotranspiration rates and to apply a uniform water depth throughout the irrigation unit.

Small farmers, with few exceptions, work the land and irrigate following a "model" or pattern - which was inherited from their elders - that does not take into account the characteristics of each soil type and of each micro-climate and water requirement variations throughout the crop cycle. In general, they lack the adequate infrastructure to improve water management.

Another reason for the low irrigation efficiency in small farms is the lack of coordination between the administrative canal rotation system and the internal irrigation water rotation system. This situation worsens in the case of horticultural crops with surface roots where severe water losses take place at farm level due to deep percolation.

While the rotation system in the network is from 10 to 12 minutes per ha, the time required to apply a water depth of 150mm to 1 ha is 3 to 4 hours. This calls for the need to apply in each irrigation very heavy water depths which render very low efficiencies due to excessively high flows.

When analyzing the results obtained in the efficiency-property size correlation, it can be clearly seen that properties of less than 10 ha yield very low EAP values (about 30%), while larger properties yield values close to 55% .

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