Irrigation Efficiency as a Measurement Factor of Farmers' Performance in Irrigation Systems

Walter Olarte Hurtado[24]

ABSTRACT

THIS PAPER IS part of the sociotechnical research on irrigation water use and management conducted in the High Andes communities (Province of Acomayo, Department of Cusco) during 1987–1990. It aims to show how irrigation efficiencies attained by the farmers constitute a measurement factor of the performance of Farmer-Managed Irrigation Systems (FMIS). To this end, two communities were selected both of which practice subsistence agriculture (in which production is destined for self-consumption with the surplus sold in the market). The Choseccani community has a traditional irrigation infrastructure, while the Santo Domingo community has an improved irrigation infrastructure.

In both communities all the farmers are irrigation water users. Twenty Choseccani and thirty Santo Domingo families were chosen at random. An inventory of their farms reveals that among the former, the number of irrigated plots per family ranges from 1 to 6 (0.12 hectare [ha] per family), whereas in the latter the number of irrigated plots per family ranges from 1 to 10 (0.80 ha). It may be observed that there is greater uniformity in irrigated plots per family in Choseccani.

Irrigation evaluations yield conveyance, distribution and application efficiencies in the order of 84.4 percent, 72.0 percent and 60.5 percent, respectively, and an overall efficiency of 35.4 percent for the Choseccani community, while the figures corresponding to the Santo Domingo community were 77.6 percent, 64.97 percent and 39.0 percent, with an overall efficiency of 20.1 percent.

Given the same labor availability in both communities under study, the system with less water irrigates more efficiently. The quality of the irrigation infrastructure does not improve efficiency when the social organization is rather weak. Finally, irrigation management in the hands of farmers with fewer plots is less efficient in the improved irrigation system, as the increase in irrigation volumes exceeds their use and management capacity.

BRIEF DESCRIPTION OF THE STUDY AREA

The study area comprises the Pomacanchi and Acopia districts in the province of Acomayo in the Department of Cusco located between $71^{0}28'$ and $71^{0}40'$ longitude W and $13^{0}58'$ and $14^{0}00'$

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[24] Agricultural Engineer. Researcher at IIUN. Professor at the School of Agriculture and Zootechnology, National University of Cusco.

latitude S at 3,700 and 4,000 m, respectively above mean sea level; the total area of the Santo Domingo community is 1,869 ha and that of Choseccani is 1,095 ha.

The average annual temperature is 11.9^{0}C, with a minimum of -4^0 C in June and a maximum of 22^{0}C in October. Mean annual relative humidity is 58 percent, ranging between 52 percent in September and 70 percent in February. There are 2,261 hours of sunlight a year. Mean annual rainfall is 827.5 mm; the highest rainfall is in January with 175.5 mm and the lowest in June with 2.1 mm. Potential evapotranspiration reaches 1,184.3 mm/year, with a maximum 11.7 mm in October and a minimum 83.4 mm in June.

The hydrological year is divided into two well-defined seasons: a humid season, December to March, with 75 percent annual rainfall, and a dry season, March to August. The climate in the region may be classified as subhumid to semiarid while, according to L.R. Holdridge's bioclimatic diagram, it belongs to the bh-Ms life zone.

Soils are of the "epipedion ocrico" type; their texture is clayey-loam, and their pH ranges from 6.0 to 7.9. The cationic exchange capacity (CIC) ranges from 7.8 to 36.4 meq/100; the salt content is low (110 mmhos/cm^2), as is the organic matter content (2%). Nutrients are N = 0.7 percent (poor), P = 0.6 percent (P2 O5) (low), and K = 2.1 percent (medium). They may thus be considered as soils of low to medium fertility. The slope of the irrigable areas ranges from 2 to 10 percent. Both communities draw water for irrigation from a main river. Gauges during low water periods range from 48 l/sec in Santo Domingo to only 12 l/sec in Choseccani.

THEORETICAL APPROACH

There is no research on this subject, especially on traditional irrigation technology. However, some conclusions have been drawn concerning the social organization for irrigation water management. L. Selligman (1986) states that good performance of irrigation systems depends upon the strength of the social organization: *Where the community is well-organized, performance is good, but where the organization loses strength, performance is poor.* Poor water management resulting from excessive use is evident in cases where community control and system maintenance are very weak.

Some authors such as Golte (1980) point out that the greater the water scarcity, the better the conditions to organize a centralized system: *Water shortage leads to community interests directing all cropping-related matters; therefore, the degree of cohesion and centralization of the decisions is dependant upon the degree of scarcity of the resource.* In this respect, C. Fonseca agrees that water abundance requires only canal maintenance and that community-individual interdependence does not exist (Gelles 1983). However, Guillet and other researchers hold that water management systems appear to be a function not only of physical factors (lack of humidity) but also of sociological factors (family autonomy). Following this trend, Grondin (1986) states that irrigation infrastructure would benefit each farmer in a different way. Finally, Gonzalez E. points out that despite inequities, all farmers obtain greater productive benefits than they would without the infrastructure and certain Andean community regulations on water distribution (Grondin 1986).

J.V. Kessel holds that the rational objective of water use in the Upper Andes is to ensure the production of foodstuffs. Farmers assume potential capital investment risks by constructing simple infrastructure systems, designed according to the location and size of their farms that ensure an equitable water distribution (Gelles 1983).

It is imperative that technical explanations to the statements made by the social scientists be found. In this way, the objective and empirical evaluation of irrigation efficiencies could explain users' attitudes.

SOCIOTECHNICAL CHARACTERISTICS OF IRRIGATION IN THE COMMUNITIES UNDER STUDY

Irrigated Land Tenure

The values given in Table 1 show that all the families use irrigation water: some farmers own up to ten irrigated plots, while others have only one (Santo Domingo). On the other hand, there are farmers in Choseccani who own one parcel and farmers who own six. Farmers with less irrigated land may be expected to be more efficient.

Table 2 shows that the average irrigated land tenure in Santo Domingo is 3.62 plots with 0.61 ha. Of these, farmers with 1 to 3 plots have an average of 0.45 ha and those with 4 to 6 plots an average of 0.76 ha. Only 3 farmers possessing 7 to 10 plots had an average of 9.7 ha. Because of their small number, they were not taken into account in the statistical calculations. In Choseccani, on the other hand, each family owns an average of 3.35 plots with 0.45 irrigated hectares; farmers with 1 to 3 plots have an average 0.27 ha and those with 4 to 6 plots have 0.63 ha. There are no farmers with more than 6 plots. When comparing these values, it may be observed that farmers with 1 to 3 plots in Santo Domingo have twice the area of those in Choseccani, although the number of plots is the same. There are no significant differences between farmers with 4 to 6 plots.

Family Size and Labor Force

Table 3 shows the size of the nuclear family (resident and nonresident members) and the total labor force, which includes all family members over 6 years of age. It also shows the adult labor force, including all family members over 18 years of age. There are no significant differences between the two communities. In Santo Domingo, the size of the nuclear family is 5.5 members of which 4.4 are resident and 1.1 migrates. The total average labor force among resident members is 3.6 while the adult labor force is 2.3. In Choseccani the size of the nuclear family is 6.0 members of which 4 are resident and 2 migrate. The total labor force is 3.4 and the adult labor force is 2.4. The two communities present similar labor force conditions.

Under these circumstances, it is may be expected that — given the same labor force availability and provided the other intervening factors remain constant — irrigation efficiency will also be similar in both communities.

Water Flows and Volumes Available at Community Level

There is a manifest difference in flows and volumes available in the two communities in the months when crops are irrigated. In the peak month of October in Santo Domingo, water availability is three times that in Choseccani.

According to some social scientists, greater water availability entails greater waste and less care. Therefore, lower irrigation efficiency may be expected in Santo Domingo, as water availability from both natural sources and the reservoirs built by the farmers is greater.

Table 1. Number and area of irrigated and dry-farmed plots.

Family number	Irrigated plots		Dry-farmed plots	
	Number of plots	Total area (ha)	Number of plots	Total area (ha)
Sto. Domingo				
1	5	0.83	10	2.31
2	4	0.74	4	1.16
3	5	1.32	7	1.98
4	4	0.11	10	0.53
5	6	0.74	5	0.99
6	10	2.06	6	1.98
7	3	0.33	5	0.83
8	4	0.37	14	2.15
9	2	0.66	13	2.89
10	4	0.44	10	1.63
11	10	1.57	11	1.57
12	4	0.38	6	1.24
13	3	0.39	7	1.22
14	1	0.17	4	0.58
15	3	0.58	9	2.23
16	4	0.66	10	1.65
17	5	0.74	8	1.82
18	4	0.91	7	2.15
19	4	0.58	8	1.82
20	2	0.50	12	2.31
21	9	2.15	5	1.82
22	3	0.33	5	0.41
23	3	0.53	11	1.98
24	5	1.44	10	2.89
25	6	0.75	11	0.81
26	2	0.24	11	1.27
27	6	1.49	12	3.55
28	5	0.44	9	0.86
29	3	0.74	5	2.64
30	5	0.58	7	1.57

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Family number	Irrigated plots		Dry-farmed plots	
	Number of plots	Total area (ha)	Number of plots	Total area (ha)
Choseccani				
1	3	0.26	5	0.25
2	2	0.33	4	0.50
3	3	0.41	5	0.69
4	2	0.25	6	1.24
5	4	0.36	7	0.91
6	5	0.75	5	0.98
7	4	0.69	3	0.33
8	1	0.08	5	0.66
9	3	0.49	5	0.54
10	4	0.91	5	1.66
11	4	0.64	5	0.34
12	1	0.08	3	0.25
13	3	0.25	5	0.66
14	4	0.85	3	0.23
15	2	0.17	3	0.25
16	3	0.41	4	1.07
17	2	0.25	3	0.25
18	4	0.66	2	0.25
19	6	0.45	6	0.36
20	5	0.39	3	0.13

Table 2. Irrigated land tenure (per family).

Communities and farmers' groups		Number of plots	Area (ha)
Santo Domingo	-X	3.62	0.61
	SD	1.10	0.11
1 to 3 plots	-X	2.50	0.45
4 to 6 plots	-X	4.75	0.76
more than 7 plots	-X	9.70	1.93
Choseccani			
1 to 3 plots	-X	3.35	0.45
4 to 6 plots	SD	0.90	0.14

Table 3. Nuclear family and labor force size.

Community		Nuclear family size			Labor force	
		Total	Resident	Non-resident	Total	Adult
Sto.Domingo	-x	5.5	4.4	1.0	3.6	2.3
	SD	1.2	1.7	0.5	1.0	0.5
Choseccani	-x	6.0	4.0	2.0	3.4	2.4
	SD	0.6	0.9	0.4	0.4	0.5

Table 4. Available flows (l/s) and volumes (m^3).

Community	Data	Months				
		August	September	October	November	December
Sto.Domingo	Flow	48	58	70	105	156
	Volume	128,568	150,336	187,488	272,160	417,830
Choseccani	Flow	12	17	22	36	58
	Volume	32,141	44,064	58,925	93,312	155,347

Irrigation Infrastructure

The irrigation infrastructure in Choseccani is traditional, that is, it was systematically planned, designed and built by the farmers according to their increasing water needs. They themselves defined their irrigation regulations and chose their water authorities. The construction materials are manufactured in the area and the works are quite simple; flows are regulated by piling up stones, a structure which, in case of deterioration, is easy and cheap to repair. But with these simple catchments the total available flows cannot be diverted. The irrigation infrastructure in Santo Domingo, on the other hand, is the result of two technologies: a traditional one similar to that of Choseccani, and a modern one. The initial planning, design and construction were performed by an extra-communal agency. It was necessary to introduce new construction materials (Portland cement and iron) and technology to be used in combination with some of the locally manufactured materials. Though Portland cement structures prevail, distribution structures are still traditional. As these works were only recently built, users have not been encouraged to devote time and money in maintenance, management and rehabilitation activities, with the exception of those which demand urgent attention. To this we should add the lack of training in the operation of the new system. Therefore, irrigation infrastructure helps determine irrigation quality inasmuch as it provides the minor works required for water diversion, conveyance and distribution. In view of the above, Santo Domingo is likely to be the one to achieve higher irrigation efficiencies.

Technical Aspects

At present, both communities use gravity and flood irrigation methods. The irrigated plots have very peculiar characteristics: they are small areas located close to the farmers' dwellings and they

are enclosed by trees for protection against thieves and possible damage by animals and frosts. There are usually from one to seven different crops grown in these plots. Traditional production technology (manual tools, animal traction, limited use of pesticides and fertilizers, etc.) is used and harvests are almost always guaranteed, unless severe frosts or hailstorms occur.

The first and only irrigation is done to prepare the soil, sow and store humidity to meet all crop needs until the rainy season. In other words, it is saturation irrigation. When the rains are delayed, additional irrigation is occasionally done. This practice, however, is not common because farmers fear that subsequent rains may result in the asphyxiation of the crops, in the proliferation of diseases, or in the main irrigated crop (beans) prolonging its vegetative cycle and exposing it to early frosts. Finally, in rainy years, the irrigation infrastructure is not used to capacity.

Socio-Organizational Aspects of the Communities under Study

The level of community organization for irrigation purposes is measured as in compliance with established rules. Table 5 contains some socio-organizational variables to provide an idea of the different levels of organization in the two communities.

Table 5. Socio-organizational variables for irrigation purposes.

Variables	Santo Domingo	Choseccani
Everybody has irrigation rights	Yes	Yes
Community determines irrigation period	Yes	Yes
Community elders accorded priority when distributing turns	No	Yes
Water distributed according to rotation until plot irrigation is complete	Yes	No
Irrigation turns complied with	Yes	Yes
	(Frequent water theft)	
Theft punished	No	Yes
Maximum irrigation area per turnout	No	Yes
Night irrigation permitted	No	Yes
Users' committees deal with conflicts	Sometimes	Yes
Irrigation charge complied with	Sometimes	Yes
When turn is missed, farmers wait for the next one	Sometimes	Yes

The most outstanding variable is the one that shows that in Santo Domingo a turn permits the irrigation of a plot, whatever its size. In Choseccani, on the other hand, each turn permits the irrigation of 0.33 ha. In the latter case more efficient irrigation is to be expected.

EFFICIENCY LEVELS

In Santo Domingo, water is conveyed through lined canals whereas in Choseccani it is conveyed through earth canals. Evaluation yields average values of 77.6 percent and 84.7 percent, respectively, which show that lining does not always improve conveyance efficiencies when there are organizational and maintenance problems. However, the lowest efficiencies (74.8%) are found among the Santo Domingo farmers who have a smaller number of irrigated plots. Higher efficiencies (85.8%) are attained in Choseccani. Water distribution from the main canal intake to the farm is done by earthen canals in both communities and rather high volumes are lost. Under these conditions, distribution efficiencies are 64.9 percent in Santo Domingo and 70.42 percent in Choseccani. There is also a substantial difference between farmers in Santo Domingo with smaller irrigated areas and efficiency values of 62.0 percent and those in Choseccani with efficiency values of 73.2 percent.

Application efficiency depends on farm management. In Santo Domingo efficiency value is 39.0 percent while in Choseccani it is 58.8 percent.

Finally, total efficiencies yield values of 19.2 percent for Santo Domingo and 34.6 percent for Choseccani, variability ranging from 58.2 percent and 54.9 percent, respectively. This shows that in both communities there are farmers with good irrigation management practices.

CONCLUSIONS

1. When the same labor force is available, the system with less water availability (Choseccani) attains higher efficiency and vice versa; Santo Domingo, with greater water availability, attains lower efficiencies. Thus, Golte's and Fonseca's hypotheses are confirmed: resource management is the best way to structure the organization in a centralized manner.
2. The quality of the irrigation infrastructure as a factor to improve irrigation efficiency is not always decisive. This is particularly so when the social organization of the community tends to be weak because of noncompliance with irrigation regulations. This conclusion coincides with W. Kelly's opinion.
3. There is a marked deficiency in irrigation water management, both at plot and general levels among farmers with small irrigated areas in the Santo Domingo improved system. Low efficiencies are achieved because applications far exceed the farmer's management capacity as well as the soil's water retention capacity. This is due to the fact that this system, only recently put in operation, permits farmers to increase irrigation water volumes per plot.

Table 6. Irrigation efficiencies as a function of number of plots per household: Santo Domingo.

Household number	Irrigated land		Ec (%)	Ed (%)	Eap (%)	E.Total (%)
	No. of plots	Total area				
7	3	0.33	73.5	81.8	15.7	9.1
9	2	0.66	65.2	91.6	25.1	15.0
13	3	0.39	63.7	63.5	12.6	5.1
14	1	0.17	68.9	66.4	43.1	19.7
15	3	0.58	76.4	52.4	12.7	5.1
20	2	0.50	92.1	46.7	86.4	38.8
22	3	0.33	71.5	43.9	12.8	4.0
23	3	0.55	67.9	69.4	14.3	6.7
26	2	0.24	90.4	43.3	52.9	22.1
29	3	0.74	78.1	58.2	28.4	12.6
x	2.5	0.45	74.8	62.0	30.4	13.8
SD			9.3	15.0	22.9	10.3
1	5	0.83	83.4	67.9	12.7	63.3
2	4	0.74	72.4	69.4	26.6	13.4
3	5	1.32	74.1	82.1	17.1	10.4
4	4	0.11	71.9	71.8	56.2	18.2
5	6	0.74	65.9	80.2	48.5	25.6
8	4	0.37	81.3	79.5	27.8	18.0
10	4	0.44	70.4	84.7	42.0	25.0
12	4	0.38	75.2	87.6	32.9	21.1
16	4	0.66	84.0	38.1	42.4	13.6
17	5	0.74	90.7	46.4	35.2	14.8
18	4	0.91	91.9	59.6	18.6	10.2
19	4	0.58	83.2	45.7	100.0	38.0
24	5	1.44	82.7	60.6	26.5	13.3
25	6	0.75	89.4	77.4	77.0	53.3
27	6	1.49	88.6	70.1	56.6	11.5
28	5	0.44	79.1	66.6	25.0	11.5
30	5	0.58	76.6	75.6	70.0	44.0
x	9.7	1.93	70.9	70.6	35.1	20.8
SD			4.8	9.5	20.1	17.4
Community average			77.6	64.9	39.0	19.2

Table 7. Irrigation efficiencies as a function of number of plots per household: Choseccani.

Household number	Irrigated land		Ec (%)	Ed (%)	Eap (%)	E.Total (%)
	No. of plots	Total area				
1	3	0.26	77.8	68.9	84.3	41.3
2	2	0.33	80.5	74.3	40.7	24.3
3	3	0.41	94.7	60.1	77.1	43.9
4	2	0.25	90.7	38.5	46.0	16.0
8	1	0.08	89.1	78.2	56.3	39.2
9	3	0.49	84.1	78.6	21.6	14.3
12	1	0.08	81.1	71.7	100.0	58.1
13	3	0.25	99.0	76.5	88.7	67.2
15	2	0.17	89.7	86.5	44.6	34.8
16	3	0.41	76.5	84.0	38.7	24.9
17	2	0.25	81.2	88.1	37.9	27.1
x	2.3	0.27	85.8	73.2	57.8	35.6
SD			6.9	13.4	24.3	15.9
5	4	0.36	87.8	78.8	64.1	44.4
6	5	0.75	87.7	28.8	100.0	25.3
7	4	0.69	90.3	73.3	39.9	26.4
10	4	0.91	84.5	39.1	16.4	12.3
11	4	0.64	87.5	85.5	59.0	44.1
14	4	0.85	79.9	64.8	81.6	42.2
18	4	0.66	87.2	68.7	45.5	27.3
19	6	0.45	69.7	78.7	100.0	54.9
20	5	0.39	73.5	86.8	52.6	33.6
x	4.4	0.63	83.5	67.5	59.7	33.5
SD			7.1	20.3	26.9	12.7
Community average			84.7	70.4	58.8	34.6

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