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Review. The evolution of research regarding the economics of irrigation water

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Abstract

This work analyses the main research trends (subjects, methodology used, countries of the authors and data) in the economics of irrigation water during the last 10 years (2000-2009). For this purpose, a quantitative methodology has been used which is new to this sphere, based on the review of a representative sample of 332 papers published in the 15 most important journals focused on this field of science indexed in the databases of the *Institute for Scientific Information* (ISI), the *Science Citation Index* (SCI) and the *Social Science Citation Index* (SCCI). The results obtained confirm: a) the notable growth in the number of papers published, especially in the last three years, b) the high degree of collaboration between authors, including those of different origin, for their performance c) the prominence of the USA, Australia, India and Spain as the countries of the first authors and origin of the data, d) the greater attention given to subjects related with «investment project analysis», «production planning» and, especially, «production function and productivity of water», and e) the predominance of empirical studies that use basic analysis approaches (cost analysis, investment evaluation, etc.).

Additional key words: literature review; quantitative approach; research methods; subject areas.

Resumen

Revisión. Evolución de la investigación en economía del agua de riego

El presente trabajo analiza las principales tendencias de investigación (temáticas, metodologías utilizadas, países de los autores y de los datos) en economía del agua de riego en los últimos 10 años (2000-2009). Para ello, se ha utilizado una metodología cuantitativa, novedosa en este ámbito, basada en la revisión de una muestra representativa de 332 artículos publicados en las 15 revistas más importantes en este ámbito científico, indexadas en las bases de datos del *Institute for Scientific Information* (ISI), el *Science Citation Index* (SCI) y el *Social Science Citation Index* (SCCI). Los resultados obtenidos confirman: a) el notable crecimiento del número de artículos publicados, sobre todo, en los tres últimos años, b) la elevada colaboración entre los autores para su realización, incluso de diferente procedencia, c) el protagonismo de EEUU, Australia, India y España como países de los primeros autores y de procedencia de los datos, d) la mayor atención prestada a los temas relacionados con el «análisis de proyectos de inversión», la «planificación de la producción» y, especialmente, a las «funciones de producción y la productividad del agua», y e) el predominio de los trabajos empíricos que utilizan técnicas de análisis básicas (análisis de costes, evaluación de inversiones, etc.).

Palabras clave adicionales: aproximación cuantitativa; áreas temáticas; métodos de investigación; revisión de la literatura.

Introduction

It is no coincidence that from the origin of the first human civilisations (Mesopotamia, Egypt, etc.) the same driving force was concealed; irrigated agriculture. Indeed, only when human beings learned to combine adequately the factors of labour, land and water could the necessary food surpluses be generated to allow the specialisation of labour and trade. Since antiquity, the use of water in agriculture has been a basic element for the survival and economic and social progress of humanity. This explains why, since then, the irrigated area of the world has not ceased to grow,

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until reaching today 280 million hectares (FAO, 2009a), making irrigation a key element for feeding the planet (World Water Assessment Programme, 2009).

The efforts of the human being have always been directed towards altering the natural water cycle for the purpose of transforming water resources in their natural state into a production factor that could be used in agricultural production processes*, i.e.,* converting «natural» or «raw» water into «available» or «usable» water. However, the use of water resources in irrigation has always generated costs, both in capital and in maintenance. On the other hand, the increase in the population accompanied by growth in the irrigated area has led to greater pressure on the available water resources, making water a scarce resource and susceptible to alternative uses by other non-agricultural users. Both circumstances characterise irrigation water as an economic asset, an object of attention of economic science.

Thus, until recently, the economics of irrigation water has been dedicated to calculating its marginal productivity («shadow» price) in agricultural production functions (Hexem and Heady, 1978), and on this basis to determine the financial viability of making new investments in order to increase the availability of water for this production activity (Clark, 1970; Carruthers and Clark, 1981; Hazelwood and Livingstone, 1982; Kindler and Russell, 1984). The ultimate objective of the literature existing until then was the availability of adequate instruments of analysis in order to maximise the profit to irrigators via the efficient use of the resource (optimisation of the provision of irrigation to crops, the distribution of the resources between different crops or the investments to be made in irrigation infrastructure), taking into account only the private costs generated by the use of the water.

From a public perspective, during these years irrigation water was considered an element of economic development that should be benefited from in order to remove a large part of the rural population from poverty and backwardness (Jones, 1995). During practically the whole of the twentieth century, public intervention in this sphere was characterised by the implementation of the so-called «supply-side policies», aimed at a continuous increase in the availability of water for irrigation, ignoring to a large extent the environmental and social costs of such actions.

However, since the 1980's, a change has begun to be perceived in the situation, with a visualisation of the first symptoms of exhaustion of the abovementioned supply-side water policy model. As Randall (1981) describes, the most developed countries, where irrigation systems had evolved with greater intensity, began to enter a phase of «mature water economy», characterised by: a) the concurrence of a high and growing demand, b) strong competition between different uses, both agricultural and non-agricultural, c) a rigid offer in the long term due to the high costs of possible new infrastructure works, d) an obsolescence in various already existing hydraulic infrastructures, and e) the appearance of serious negative environmental externalities as a consequence of the alterations in the natural water regime (reduction of the flow of rivers, pollution of water bodies, overexploitation of aquifers, etc.).

This situation, more and more extended across the whole planet, has revealed the growing scarcity of water, and is causing an intense social and political polemic regarding efficiency in the use of this resource by agriculture. Hence, the apparently bad management of water in irrigation (large water «losses» owing to low technical efficiency, generation of low added value in relation to other uses and the generation of negative environmental impacts) has served as an argument to justify a review of water and irrigation policy towards a new «demand model», aimed at improving the conservation of the limited resources available. In this way the main guideline for public intervention is no longer economic development but «sustainable development» (Svendsen, 1987; Letey, 1994; Oster and Wichelns, 2003).

Within this new focus, more concerned by the growing postmaterialist demands of modern societies (different from the simple satisfaction of basic needs such as food), multiple new challenges are posed to the scientific community on the subject of irrigation water. Thus, in recent years, new lines of research have appeared on the economics of irrigation water. These lines analyse the conflicts and synergies between the different political objectives proposed regarding irrigation water (the economic objectives of efficiency, social objectives of equity and environmental objectives of sustainability), as well as the most appropriate manner of implementing the different public policies related to the «governance» of water with the aim of optimising, not now the private benefit of the irrigators, but the degree of well-being of society as a whole.

Recently, studies on a great diversity of themes have emerged with strength. Among others, and without wishing to be exhaustive, the following can be quoted: a) the environmental (non-point source pollution, salinity, overexploitation of aquifers) and macroeconomic (virtual water trade, water footprint) implica-

tions of agricultural water use, b) the social (labour market and rural development) implications of irrigation in an ever more diverse rural environment, c) the advantages and inconveniences of different economic instruments designed for the purpose of improving the allocation of water inside and outside the agricultural sector (metering, water markets, promotion of technological innovation, etc.), d) the interactions that exist between the different policies related with the public management of water, mainly between agricultural and environmental policy, e) the future perspectives of water availability and requirements taking into account climate change and global food demand issues, f) the functioning of public and private institutions related with irrigation water, and g) the implications for irrigation of the new legal rules approved in response to the «new water culture» prevailing in society (*e.g.,* the Water Framework Directive in Europe).

The topicality and dynamism of the economics of irrigation water justify the convenience of carrying out a study on the sate of the art in scientific literature. In this respect, this work attempts to make a contribution by carrying out a review of the papers that have appeared recently on this branch of knowledge. Therefore, its ultimate aim is to respond in a quantitative manner, among others, to the following questions: which subjects within the economics of irrigation water are the most recurrent in the literature during the last ten years? Which countries currently lead research in this field? Which methodologies are the most used? In this way, this document hopes to be of interest to many researchers involved in the sphere of agricultural sciences, engineering and economics, generating useful information on which will be the future lines of research in this latter sphere (emerging subjects) and how to improve the quality of the scientific work performed within the same (adaptation of methodologies and empirical applications).

Material and methods

Studies abound in academic literature aimed at knowing the dominant lines of research in different disciplines. Traditionally these studies have been carried out using qualitative techniques based on the reflection and accumulated knowledge of experts and, therefore, not exempt from a certain subjectivity. However, it is becoming more frequent for studies of this type to be carried out using empirical methods and results supported by the analysis of published work, precisely the technique on which this work is based. Specifically, the methodology used is supported by the analysis of the papers published in the main areas in which journals are found related with the economics of irrigation water.

This methodology has been widely used to identify the main lines of research in disciplines such as management (Mentzer and Kahn, 1995; Scudder and Hill, 1998; Acedo *et al*., 2001; Carter and Ellram, 2003; Ventovuori *et al*., 2007) and marketing (Ngai, 2003; Martín-Ruiz *et al*., 2006; Schibrowsky *et al*., 2007; Das, 2009), contrary to what has occurred in agricultural economics or the economics of natural resources. In these disciplines, the few studies carried out have been supported by techniques of a qualitative type (*e.g.* Garrido, 1995), owing to which the study presented here represents a novel contribution in the sphere of both disciplines.

The main aspects to be dealt with in the methodology are: a) the period analysed, b) the selection of journals considered «source», c) the selection of papers, and d) the classification criteria of the same. Each one of these points is commented on below.

Period analysed

The period to be reviewed comprises the last 10 years; the period which extends from the year 2000 to 2009. The choice of this first decade of the 21 century as the analysis period appears to be justified for two main reasons. In the first place owing to the «youthfulness» of the branch of knowledge on the economics of irrigation water, which means that greater development of the same in its different aspects has been made during recent years (Garrido *et al*., 2009). In the second place it is appropriate to emphasise that it has also been during this decade that key events have occurred which have motivated an unwonted social and political interest in relationship with the themes of the economics of irrigation water: the first effects of climate change and the concern for the future availability of water resources (Rosenzweig *et al*., 2004; Iglesias *et al*., 2007; IPCC, 2007; Rosenzweig *et al*., 2008), the approval of the Water Framework Directive as a regulatory environmental principle of the European Union (Berbel and Gutiérrez, 2004), the worsening of the world food crisis (UN, 2008; FAO, 2009b), etc. All of these circumstances are making the growing scarcity

of the resource more evident, in both social (greater demand for consumption) and hydrological (less physical availability) terms, making it more and more necessary for studies to be carried out from the economic perspective, as the science responsible for the analysis of scarce resources and their alternative uses.

Population of papers considered

The population analysed here is made up of papers related with irrigation economics indexed in the databases of the *Institute for Scientific Information* (ISI), the *Science Citation Index* (SCI) and the *Social Science Citation Index* (SCCI). The selection process to achieve these papers was made by introducing a search criteria in the above-mentioned databases using the descriptors *«Economic»* and *«Irrigation»,* obtaining 1,536 papers for the above-mentioned period.

Selection of journals

The journals selected for the review of the literature were initially those which are specifically related with agriculture and water. Specifically, the four most representative subject areas of the ISI considered for this purpose have been: *«Water resources», «Agronomy», «Agriculture multidisciplinary»* and *«Agricultural economics and policy»*. Given the large number of titles obtained from the aggregation of these four subject areas (151 journals and 919 papers in total), the selection of journals has been redefined. In order to choose only the most relevant journals dealing with the economics of irrigation water, a stricter criterion has been taken into account, considering only those that contain more than 5% of the papers published over each subject area. Following this criteria 17 journals have finally been selected, as detailed in Table 1.

Selection of the sample of papers

The sample of papers initially considered for the empirical analysis has been the ones included in the population (1,536 papers) published in the most relevant journals in this topic (17 journals), as shown in the second column of Table 1. This sample comprised 443 papers.

After reviewing the content of these papers, 111 were erased form the database since it was considered that their subject matter was not really related to the economics of irrigation water. Thus, the sample finally taken for the empirical work was formed by 332 papers.

Considering sample and population sizes ($n = 332$ and $N = 1,536$), it can be confirmed that the sampling error considered is $< 5\%$ (4.8%) with a confidence level of 95%, guaranteeing an adequate representation of the population studied.

Finally, it is worth mentioning that the authors are conscious of the subjectivity of some of the criteria used for the selection of journals and papers. However it must be stated that such a circumstance is consubstantial to this type of work[1]. In any case, what is really relevant is that the sample of work selected should be representative of the state of the art on the subject of the economics of irrigation water, as it is appropriate to deduce from the procedure followed.

Classification criteria of the papers

For the carrying out of the subsequent analysis, a database has been prepared in which each paper has been classified according to different criteria. In this respect the most relevant are those regarding the year of publication, the subject analysed, the methodology followed and the geographical sphere of the authors and of the empirical data used.

Based on the analysis of the literature and other review works carried out previously (Dinar and Zilberman, 1991; Garrido, 1995; Schoengold and Zilberman, 2007; Gómez-Limón *et al*., 2009; Tsur, 2009) the classification of subjects has been established as it appears in Table 2. Thus, six general subjects have been established (institutional framework, irrigation and productive system, economy of inputs use, economic instruments, irrigation and environment and others), which in turn are broken down into 31 more specific subjects.

[1] In order to check this circumstance, similar works regarding other fields of science can be consulted. Just as examples, the following can be quoted: Ngai (2003), where a sample of 270 papers from 3 journals was used; Ventovuory *et al.* (2007), where 584 papers from 4 journals were considered; Svensson and Wood (2007), who analysed 811 papers from 3 journals; Sachan and Datta (2005), who reviewed a sample of 442 papers from 3 journals.

Table 1. Scientific journals and papers selected

Subject areas/Journal	No. of selected papers	Percentage over the subject area	Percentage over the whole set of selected papers
1. **Water Resources** (60 journals and 538 papers)	261	49.00	58.92
11. *Agricultural Water Management**	117	21.75	26.41
12. *Irrigation and Drainage**	55	10.22	12.42
13. *Journal of Irrigation and Drainage Engineering*	30	5.58	6.77
14. *Water Resources Management*	30	5.58	6.77
15. *Water Science and Technology*	29	5.39	6.55
2. **Agronomy** (49 journals and 334 papers)	199	59.58	44.92
21. *Agricultural Water Management*	117	35.03	26.41
22. *Irrigation and Drainage*	55	16.47	12.42
23. *Agronomy Journal*	27	8.08	6.09
3. **Agriculture Multidisciplinary** (35 journals and 152 papers)	85	55.92	19.19
31. *Agricultural Systems*	30	19.74	6.77
32. *Indian Journal of Agricultural Sciences*	24	15.79	5.42
33. *Agriculture Ecosystems & Environment*	11	7.24	2.48
34. *Australian Journal of Experimental Agriculture*	11	7.24	2.48
35. *Journal of Sustainable Agriculture*	9	5.92	2.03
4. **Agricultural Economics and Policy** (9 journals and 80 papers)	70	87.50	15.80
41. *Agricultural Economics*	19	23.75	4.29
42. *Australian Journal of Agricultural and Resource Economics*	17	21.25	3.84
43. *Journal of Agricultural and Resource Economics*	14	17.50	3.16
44. *American Journal of Agricultural Economics*	10	12.50	2.26
45. *Food Policy*	6	7.50	1.35
46. *European Review of Agricultural Economics*	4	5.00	0.90
Total 151 journals and 919 papers	443		

* The journals Agricultural Water Management and Irrigation and Drainage are included in two subject areas «Water Resource» and «Agronomy».

Regarding the methodology of the study the classification of Table 3 has been used.

When geographically referencing the institutions where the authors work and the areas where they have carried out the empirical studies, the classification of geographical areas that appears in Table 4 was used.

Methods

In order to analyse the relationships existing between different categorical variables, an analysis has been performed of cross tables, based on Pearson's χ^2 contrast. In the first place, this statistical test was applied to all the $m \times n$ contingency tables (m rows × n columns) corresponding to different categorical classification variables considered. Where this test was significant (an association exists between the variables analysed) a second contrast was made also based on the χ^2 test on 2 × 2 contingency tables (2 rows × 2 columns) constructed to analyse the particular significance of each one of the cells of the original $m \times n$ tables. These new 2 × 2 tables have been constructed considering the dummy variables (1 = present the attribute of the cell

Table 2. Subjects considered for the typology of papers

General	Specific
1. Institutional framework	11. Water Framework Directive 12. National water laws 13. Hydrologic Planning 14. Institutions for water management 15. Others
2. Irrigation and productive system	21. Irrigation and economic development 22. Virtual water and water footprint 23. Others
3. Economy of inputs use	31. Analysis of water investment projects 32. Production function and inputs productivity 33. Production planning 34. Efficiency analysis 35. Irrigation technology 36. Irrigation and agricultural structures 37. Others
4. Economic instruments	41. Water demand and cost recovering 42. Water market 43. Irrigation infrastructure and modernization 44. Water sharing between basins 45. Groundwater management 46. Integrated water management 47. Drought management 48. Irrigation and agricultural policy 49. Others
5. Irrigation and environment	51. Quality and water pollution 52. Groundwater overexploitation 53. Salinity and drainage 54. Irrigation and environmental policy 55. Irrigation and climate change 56. Others
6. Others	60. Others

analysed, 0 = do not present the attribute of the cell analysed) which result from the transformation of the initial categorical variables. This has allowed an analysis of whether statistically significant differences exist between the observed and expected frequencies in each case.

Furthermore, since for the correct use of the χ^2 statistic the expected frequencies of < 5 should be < 20% of the total frequencies of the contingency table (Cochran, 1952), the variables have been recoded when this condition was not fulfilled. For this purpose, the number of categories has been reduced via the grouping of those that present lower frequencies.

Table 3. Methodologies considered for the typology of papers

General	Specific
1. Theoretical	1. Theoretical
2. Empirical	21. Descriptive 22. Basic analysis approaches (analysis of costs, investment evaluation, etc.) 23. Basic statistics (uni-, bi- variant) 24. Multivariant analysis and econometric methods 25. Mathematical programming 26. Others

Results

The results of the analysis of the papers on the economics of irrigation water obtained using the methodology indicated in the previous section allow us to know their distribution in accordance with the following criteria: a) years of publication and source journals, b) number and geographical area of the authors, c) geographical area where the data are obtained, d) subject areas, and e) methodology used.

Distribution by years of publication and journals

The number of papers published in the last 10 years has followed a growing trend, with average annual growth rates of around 7% during the years 2004-2006, and 11% during the last three years (2007-2009). As a consequence of this evolution the papers published from 2007 to 2009 are double those of the years 2000-2003 (Fig. 1).

The subject area that includes the highest number of papers is *Water Resources* (37.7%), followed by *Agronomy* (22.9%), *Agricultural Economics and Policy* (19.9%) and *Agriculture Multidisciplinary* (19.6)

Table 4. Geographical areas

1. Northern Mediterranean countries: Portugal, Spain, France, Italy, Greece, Turkey, Israel
2. North of Europe (rest of European countries not included previously)
3. United States and Canada
4. Rest of America
5. Oceania
6. Asia
7. Africa

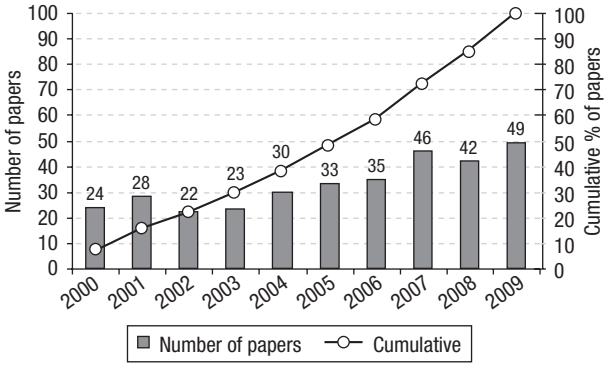

Figure 1. Distribution of the papers over time during the period 2000-2009.

(Table 5). Regarding the distribution of papers between the 17 journals, *Agricultural Water Management* is first in order of importance with 25.0%, followed by *Irrigation and Drainage* with 11.1%, *Agricultural Systems* with 7.8%, *Water Resources Management* with 7.5% and *Water Science and Technology* with 6.6%. It can be observed that four of the five journals that publish the greatest number of papers belong to the subject area of *Water Resources* (Fig. 2).

The χ^2 contrast does not reveal significant differences of any of the subject areas considered in the three periods (Table 5). Nevertheless, though not significant, it is worth commenting on the growth experienced by the *Water Resources* and *Agronomy* subject areas during the first decade of the 21st century, and the decrease of *Agriculture Multidisciplinary* in same period.

Distribution according to the number and geographical area of the authors

Number of authors

A high degree of collaboration is observed between different authors. In 86.1% of the papers more than one author participates (see Table 6). Studies carried out by more than three authors concentrate the highest share of total works (32.8%), followed by papers written by three (31.0%), by two (22.3%) and by one (13.9%). Moreover, the χ^2 contrast (Table 6) shows the rising increase in collaboration. Thus, the percentage of articles prepared by > 3 authors rose from 17.5% in the period 2000-2003 to 46.0% in 2007-2009. In contrast, the percentage of those prepared by a single author has diminished from 20.6% in 2000-2003 to 7.3% in 2007-

Table 5. Contingency table of subjects areas by period

Subject areas	Period			
	2000-2003	2004-2006	2007-2009	Total
Water Resources	33 (34.0%)	36 (36.7%)	56 (40.9%)	125 (37.7%)
Agronomy	22 (22.7%)	20 (20.4%)	34 (24.8%)	76 (22.9%)
Agriculture Multidisciplinary	22 (22.7%)	22 (22.4%)	21 (15.3%)	65 (19.6%)
Agricultural Economic & Policy	20 (20.6%)	20 (20.4%)	26 (19.0%)	66 (19.9%)
Total	97 (100.0%)	98 (100.0%)	137 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 3.477$. Significance = 0.747.

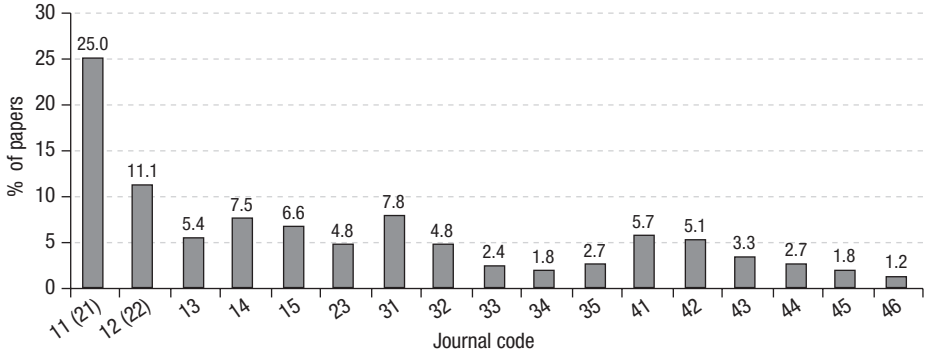

Figure 2. Distribution of the papers by journal (%). Journal codes: see Table 1.

Table 6. Contingency table of the number of authors by period

Number authors	Period			
	2000-2003	2004-2006	2007-2009	Total
1	20 (20.6%)**	16 (16.3%)	10 (7.3%)***	46 (13.9%)
2	25 (25.8%)	24 (24.5%)	25 (18.2%)	74 (22.3%)
3	35 (36.1%)	29 (29.6%)	39 (28.5%)	103 (31.0%)
> 3	17 (17.5%)***	29 (29.6%)	63 (46.0%)***	109 (32.8%)
Total	97 (100.0%)	98 (100.0%)	137 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 25.237$. Significance = 0.000. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

2009. This trend may be a reflection of the growing complexity of the subjects dealt with, which require a more multidisciplinary focus, integrating a growing number of specialists.

Geographical area and country of the authors

On numerous occasions, the origin of the authors crosses geographical frontiers with collaborations between authors from different countries. Thus, 28.6% of the papers have been published by authors from two or more countries (7.8% of them by authors from, at least, three different countries). In addition, the significance of the χ^2 statistic reveals the greater participation of authors from different countries in the period 2007-2009 than in the two previous periods (Table 7), reflecting likewise the need for transnational experiences in order to analyse the ever more complex issues of the economics of irrigation water. Despite this, there is still a strong predominance of work performed by authors from the same country (71.4%).

The geographical area of origin of the first author that includes the greatest number of papers is Asia, with 24.7% of the total, closely followed by Northern Mediterranean Countries with 22.0%, and the USA and Canada with 19.9%. These three areas host more than 60% of the institutions to which the first author belongs. With a smaller contribution, but still important, is Oceania with 15.4% (Table 8).

Table 7. Contingency table of the number of countries where authors work by period

Number of countries where authors work	Period			
	2000-2003	2004-2006	2007-2009	Total
1	74 (76.3%)	81 (82.7%)	82 (59.9%)***	237 (71.4%)
> 1	23 (23.7%)	17 (17.3%)	55 (40.1%)***	95 (28.6%)
Total	97 (100.0%)	98 (100.0%)	137 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 16.51$. Significance = 0.000. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 8. Contingency table of geographical area of the first author by period

Geographical area of the first author	Period			
	2000-2003	2004-2006	2007-2009	Total
Northern Mediterranean countries	21 (21.6%)	25 (25.5%)	27 (19.7%)	37 (22.0%)
USA and Canada	28 (28.9%)***	20 (20.4%)	18 (13.1%)***	66 (19.9%)
Oceania	6 (6.2%)***	11 (11.2%)	34 (24.8%)***	51 (15.4%)
Asia	26 (26.8%)	23 (23.5%)	33 (24.1%)	82 (24.7%)
Rest of the world	16 (16.5%)	19 (19.4%)	25 (18.2%)	60 (18.1%)
Total	97 (100.0%)	98 (100.0%)	137 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 22.835$. Significance = 0.004. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

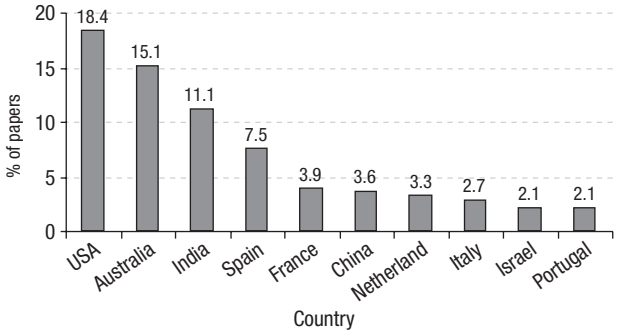

Figure 3. Distribution of the papers by country of the first author (%).

The analysis of the distribution of the papers according to the geographical area of the first author throughout the three periods analysed, reveals the continued loss of prominence of authors from the USA and Canada from 2000-2003 to 2007-2009, in favour, especially, of Oceania which undergoes spectacular growth in the period 2007-2009 (Table 8).

Although the authors come from a total of 56 countries, only 10 of them have a representation of over 2%. In this respect, the USA appears in first place with 18.4% of the studies, followed by Australia with 15.1%, India with 11.1% and, in fourth place, Spain with 7.5%. At a greater distance, and without reaching 4%, are France (3.9%), China (3.6%) and the Netherlands (3.3%). With lower percentages, between 3 and 2%, are Italy (2.7%), Israel and Portugal, both with 2.1% (Fig. 3).

Distribution by geographical area where the data are obtained

In general, the data of the empirical studies are obtained in a single country. This is the case of 96.7% of the studies sampled. Only 3.3% of the studies use data from two or more countries. The geographical area of origin of the data is concentrated on Asia which, with 33.3% of the empirical studies analysed, is almost double the second in importance, Northern Mediterranean Countries (19.0%). These two areas take in more than 50% of the studies. Next are the USA and Canada with 15.7%, and Oceania with a participation of around 12% (Table 9). These figures clearly show in which world areas the presence of scarcity or quality problems regarding water for irrigation areas are more acute.

As can be observed, the main geographical areas of study coincide with those of the first authors, with the exception of Africa which acquires a greater predominance as the origin of data than of first authors. The χ^2 contrast does not reveal significant differences of the distribution of the papers according to the geographical area of the empirical applications made throughout the three periods analysed (Table 9).

Although the data of the empirical papers originate in a total of 62 countries, only 6 of them provide more than 2% of the total. Furthermore, more than 50% are concentrated in just five countries. In first place is the USA with 15.4%, followed by India (13.4%), Australia (11.1%), Spain (7.9%), and China (7.5%) (Fig. 4). As can be observed, there is an important correlation between the countries of the first author and those of the study data, so that the first four coincide, although with India and Australia exchanging positions.

Distribution by subject areas

The subject area dealt with in almost half of the papers analysed (47.9%) is «economy of inputs use», doubling the second in importance, «economic instruments», which covers 22.9% of the studies. The rest of

Table 9. Contingency table of the geographical area of the data by period

Geographical area of the data	Period			
	2000-2003	2004-2006	2007-2009	Total
Northern Mediterranean countries	18 (20.2%)	20 (23.0%)	20 (15.4%)	58 (19.0%)
USA and Canada	17 (19.1%)	16 (18.4%)	15 (11.5%)	48 (15.7%)
Oceania	6 (6.7%)	10 (11.5%)	19 (14.6%)	35 (11.4%)
Asia	29 (32.6%)	27 (31.0%)	46 (35.4%)	102 (33.3%)
Rest of the world	19 (6.7%)	14 (9.2%)	30 (10.0%)	63 (8.8%)
Total	89 (100.0%)	87 (100.0%)	130 (100.0%)	306 (100.0%)

Pearson's $\chi^2 = 8.641$. Significance = 0.373. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

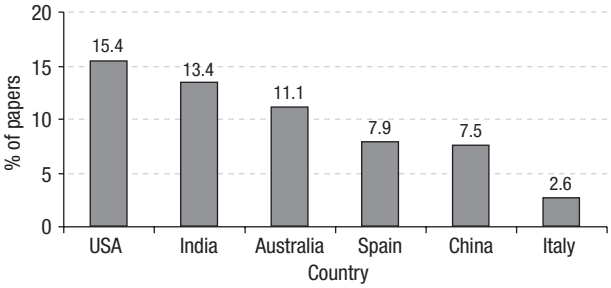

Figure 4. Distribution of the papers by country of the data (%).

the articles are distributed, almost equally, between the other three areas: «irrigation and environment» (11.4%), «irrigation and productive system» (9.9%) and «institutional framework» (7.8%), as shown in Table 10. The χ^2 contrast indicates that the proportionality of the different subject areas remains stable over time (p-value of χ^2 statistic is 0.723), as can be confirmed in Table 10.

However, crossing the variable subject area with the geographical area of the first author, some results appear to be significant (Table 11). For this contrast the significance of the χ^2 statistic reveals that the authors of Northern Mediterranean Countries, the USA and Canada give more attention to «economic instruments» and less to «irrigation and productive system». However, those of Oceania concentrate more on the areas of «irrigation and environment» and less on «economy of inputs use», whilst those of Asia dedicate more of

Table 10. Contingency table of the general subject area by period

General subject area	Period			
	2000-2003	2004-2006	2007-2009	Total
Institutional framework	5 (5.2%)	10 (10.2%)	11 (8.0%)	26 (7.8%)
Irrigation and productive system	9 (9.3%)	8 (8.2%)	16 (11.7%)	33 (9.9%)
Economy of inputs use	48 (49.5%)	51 (52.0%)	60 (43.8%)	159 (47.9%)
Economic instruments	21 (21.6%)	21 (21.4%)	34 (24.8%)	76 (22.9%)
Irrigation and environment	14 (14.4%)	8 (8.2%)	16 (11.7%)	38 (11.4%)
Total	97 (100.0%)	98 (100.0%)	137 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 5.317$. Significance = 0.723. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 11. Contingency table of geographical area of the first author and the data by general subject area

Geographical area	General subject area					
	Institutional framework	Irrigation and productive system	Economy of inputs use	Economic instruments	Irrigation and environment	Total
Of the first author						
Northern Mediterranean countries	4 (15.4%)	3 (9.1%)*	33 (20.8)	24 (31.6%)**	9 (23.7%)	73 (22.0%)
USA and Canada	3 (11.5%)	1 (3.0%)**	35 (22.0%)	21 (27.6%)*	6 (15.8%)	66 (19.9%)
Oceania	5 (19.2%)	7 (21.2%)	15 (9.4%)***	11 (14.5%)	13 (34.2%)***	51 (15.4%)
Asia	6 (23.1%)	12 (36.4%)	47 (29.6%)**	11 (14.5%)**	6 (15.8%)	82 (24.7%)
Rest of the world	8 (30.8%)	10 (30.3%)	29 (18.2%)	9 (11.8%)	4 (10.5%)	60 (18.1%)
Total	26 (100%)	33 (100%)	159 (100%)	76 (100%)	38 (100%)	332 (100%)
Of the date						
Northern Mediterranean countries	2 (10.0%)	3 (11.1%)	27 (17.6%)	18 (26.5%)*	8 (21.1%)	58 (19.0%)
USA and Canada	1 (5.0)	1 (3.7%)*	30 (19.6%)*	11 (16.2%)	5 (13.2%)	48 (15.7%)
Oceania	3 (15.0%)	0 (0%)*	10 (6.5%)	11 (16.2%)	11 (28.9%)***	35 (11.4%)
Asia	7 (35.0)	14 (51.9%)**	55 (35.9%)	15 (22.1%)**	11 (28.9%)	102 (33.3%)
Rest of the world	7 (35.0%)	9 (33.3%)	31 (20.3%)	13 (19.1%)	3 (7.9%)	63 (20.6%)
Total	20 (100.0%)	27 (100.0%)	153 (100.0%)	68 (100.0%)	38 (100.0%)	306 (100.0%)

Pearson's $\chi^2 = 40.735$. Significance = 0.001. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

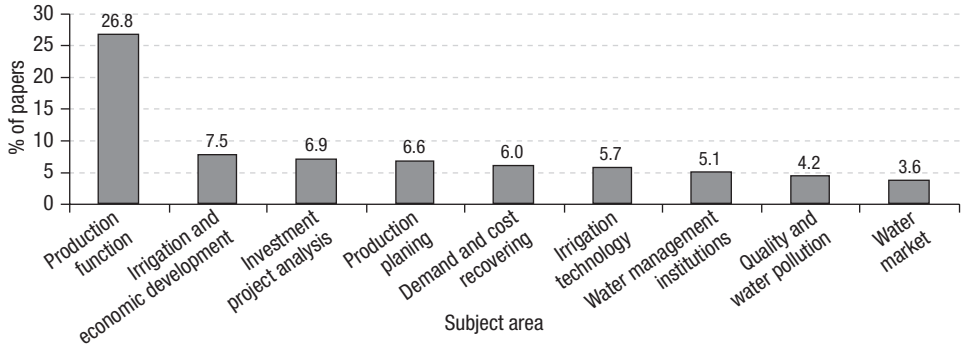

Figure 5. Distribution of the papers by specific subjetc area (%).

their efforts to subjects related with «economy of inputs use», and to a lesser extent those of «economic instruments».

The χ^2 statistic is also significant when the subject area of the data is crossed with the geographical area of the primary data. In fact, when the data come from Northern Mediterranean Countries, the USA and Canada, Oceania, and Asia, the studies are more related with the areas of «economic instruments», «economy of inputs use», «irrigation and environment» and «irrigation and productive system, respectively. Likewise, when they originate in the USA and Canada and Oceania they bear less relationship with the area of «irrigation and productive system», and those of Asia with «economic instruments» (Table 11).

Regarding the 30 specific subject areas considered, that relative to «production function» stands out from the rest with 26.8% of the papers. Next, four specific areas appear with a participation of between 6% and 8%: «irrigation and economic development» (7.5%), «investment project analysis» (6.9%), «production planning» (6.6%) and «water demand and cost recovery» (6.0%) (Fig. 5). Another four areas occupy between 3% and 6% («irrigation technology», «water management institutions», «quality and water pollution» and «water markets»).

Distribution by the methodology used

The majority of the papers that make up the study are empirical (86.7%), the rest being theoretical. This confirms irrigation water economics as an applied field of science. Among the empirical studies, the methodologies most commonly used consist of basic analysis approaches and basic statistics (cost analysis, investment evaluation, etc.), used in 36.7% of the papers, followed by mathematical programming (25.0%). To a lesser extent multivariant analysis and econometric models (10.5%) and descriptive studies (8.1%) have been used. The χ^2 contrast does not reveal significant differences of any of the methodologies used in the three periods (Table 12).

Regarding the relationship between the methodology of the studies and the geographical area of the first author (Table 13), it is worth pointing out that the

Table 12. Contingency table of the methodology used by period

Methodology used	Period			
	2000-2003	2004-2006	2007-2009	Total
Theoretical	13 (13.4%)	15 (15.3%)	16 (11.7%)	44 (13.3%)
Descriptive	7 (7.2%)	7 (7.1%)	13 (9.5%)	27 (8.1%)
Basic analysis approach and basic statistics	35 (36.1%)	42 (42.9%)	45 (32.8%)	122 (36.7%)
Multivariant analysis	8 (8.2%)	9 (9.2%)	18 (13.1%)	35 (10.5%)
Mathematical programming	26 (26.8%)	19 (19.4%)	38 (27.7%)	83 (25.0%)
Others	8 (8.2%)	6 (6.1%)	7 (5.1%)	21 (6.3%)
Total	97 (100.0%)	98 (100.0%)	137 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 6.869$. Significance = 0.738. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 13. Contingency table of geographical area of the first author by general methodology used

Geographical area of the fist author	Methodology used						
	Theoretical	Descriptive	Basic analysis approach and basic statistics	Multivariant analysis	Mathemathical programming	Others	Total
Northern Mediterranean countries	11 (25.0%)	4 (14.8%)	22 (18.0%)	2 (5.7%)**	27 (32.5%)***	7 (33.3%)	73 (22.0%)
USA and Canada	5 (11.4%)	7 (25.9%)	25 (20.5%)	8 (22.9%)	18 (21.7%)	3 (14.3%)	66 (19.9%)
Oceania	4 (9.1%)	4 (14.8%)	15 (12.3%)	10 (28.6%)**	12 (14.5%)	6 (28.6%)	51 (15.4%)
Asia	10 (22.7%)	6 (22.2%)	41 (33.6%)***	7 (20.0%)	14 (16.9%)*	4 (19.0%)	82 (24.7%)
Rest of the world	14 (31.8%)	6 (22.2%)	19 (15.6%)	8 (22.9%)	12 (14.5%)	1 (4.8%)	60 (18.1%)
Total	44 (100.0%)	27 (100.0%)	122 (100.0%)	35 (100.0%)	83 (100.0%)	21 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 37.435$. Significance = 0.010. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

chi-square statistic shows that the authors of Northern Mediterranean Countries use to a greater extent «mathematical programming» and less «multivariant analysis», a methodology which, however, is the most widely used by the authors of Oceania. The Asian authors show a preference for the use of «basic analysis approach and statistics» and rarely use «mathematical programming».

Significant differences also appear when crossing the methodology used and the subject area, since those papers that deal with «institutional framework» or «irrigation and productive system» are to a larger extent theoretical studies. When disaggregating the methodologies used in the empirical studies significant differences are also found (see Table 14). «Descriptive» methodology is used to a greater extend in studies on «irrigation and productive system». «Basic analysis approaches and basic statistics» are found principally when analysing «economy of inputs use», and «mathematical programming» with studies about «economic instruments».

Characterisation of the papers of which the first author is Spanish

Finally, it is worth commenting on some results regarding Spain. In this way, 25 out of the 332 papers included in the sample of papers considered, that is 7.5%, have a Spaniard as first author, being exceeded by only three countries: the USA (18.4%), Australia (15.1%) and India (11.1%). Regarding the general behaviour of the sample, the papers in which the first author is Spanish are characterised by:

— The highest share has been published in the period 2004-2006 (52%), when the majority of the sample as a whole was published in 2007-2009 (41%).

— They have published to a greater extent in journals of the subject area «Agricultural Economics and Policy» (28% compared to 20%) and less in «Agriculture Multidisciplinary» (8% compared to 20%).

— The publications in the journal *Agricultural Water Management* (40%) amply exceed the sample as a whole (25%).

Table 14. Contingency table of general subjects area by general methodology used

General subject area	Methodology used						
	Theoretical	Descriptive	Basic analysis approach and basic statistics	Multivariant analysis	Mathemathical programming	Others	Total
Institutional framework	12 (27.3%)***	4 (14.8%)	1 (0.8%)***	6 (17.1%)**	0 (0%)***	3 (14.3%)	26 (7.8%)
Irrigation and productive system	14 (31.8%)***	7 (25.9%)***	0 (0%)***	4 (11.4%)	4 (4.8%)*	4 (19.0%)	33 (9.9%)
Economy of inputs use	7 (15.9%)***	7 (25.9%)**	97 (79.5%)***	12 (34.3%)*	30 (36.1%)**	6 (28.6%)	159 (47.9%)
Economic instruments	10 (22.7%)	6 (22.2%)	10 (8.2%)***	8 (22.9%)	38 (45.8%)***	4 (19.0%)	76 (22.9%)
Irrigation and environment	1 (2.3%)**	3 (11.1%)	14 (11.5%)	5 (14.3%)	11 (13.3%)	4 (19.0%)	38 (11.4%)
Total	44 (100.0%)	27 (100.0%)	122 (100.0%)	35 (100.0%)	83 (100.0%)	21 (100.0%)	332 (100.0%)

Pearson's $\chi^2 = 164.740$. Significance = 0.000. Significance of Pearson's χ^2 for 2 × 2 contingency tables: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

— They present a greater tendency to collaborate, so that all of the papers (100%) have been published in collaboration with other authors, compared to 86% of the whole sample. However this collaboration takes place to a larger extent with co-authors who are also Spanish (84% compared to 63%). Of the four papers published with authors from other countries, two have been with Italians and the other two with researchers from the UK.

— The greatest attention is given to the subject area «economic instruments» (44% compared to 23%). The rest of the areas have received less interest.

— Greater attention is given to the theme «water markets» (16% compared to 4%).

— Greater use is made of methodology related with mathematical programming (59% compared to 29%) and less use is made of basic analysis approaches (23% compared to 39%) and multivariant statistics and econometric models.

Conclusions

This work has analysed the state of scientific research on the economics of irrigation water, using for this a methodology that is new in this sphere. Compared to traditional studies that have used qualitative techniques based on the contributions of experts, in this study a quantitative focus has been chosen supported by the analysis of papers published in the most relevant journals that focus on this field of science. We believe that the results obtained are of interest to the scientific community interested in research regarding the economics of irrigation water, in order to know the trends that exist regarding subjects and methodologies, as well as to quantify the relative importance of the different schools that exist on the subject. In any case, taking into account the methodological limitations of the application performed, complementary research, both from a qualitative and quantitative point of view, would be welcome in order to confirm the results obtained and to expand the analysis to include other aspects relevant to science.

Considering the results achieved, the first point worth mentioning is the growing number of papers published on the economics of irrigation water during the period analysed. This highlights the progressive concern of researchers for tackling the rising problems generated by the use of such an important and limited resource, such as water, for the economic development of a country and the well-being of its population. This is why this field of science is expected to be widened and enriched with many other studies in the forthcoming years.

Throughout the period analysed, the most recurrent topic in the literature within the economics of irrigation water has been the «economy of inputs use», which covers almost half of the papers, and specifically those related with production functions and productivity of water (more than a quarter of the whole sample analysed), followed by those focused on «investment project analysis» and «production planning». These results confirm the suspicions expressed in the introduction to this study regarding the lines of research that have traditionally attracted the most attention regarding the economics of irrigation water in a productivist context.

The second most important subject area is «economic instruments», with almost a quarter of the papers, where the studies dedicated to demand and cost recovery analysis especially stand out. This line is the one that has received the most attention in the last three years, which highlights the growing importance granted to the improvement of water management (increase the efficiency, minimize environmental impacts, etc.) in a scenario of increasing scarcity.

Statistic analysis has not given any significant clue about which topics will be the most relevant ones in the future. However, the authors' experience and common sense allow us to hypothesise that «economic instruments», «irrigation and environment» and «institutional framework» will be the predominant issues in the academic debate in the next decade, as the leading subjects for mature water economies applying demand policies, aiming to solve problems related with the governance of water resources.

Water scarcity and quality problems do not affect all countries with the same intensity. In this sense it has been confirmed that those countries with more severe water problems are the leading ones in the field of the economics of irrigation water. In fact, the ranking based on the origin of the first author is led by the USA, followed by Australia, India and Spain. Regarding this point, it is also worth noting how other countries that also have acute water problems are absent in this ranking, as is the case of developing countries in Africa and Asia. This probably reveals a lack of institutions and limited resources available for R + D.

Dealing with the authorship of the papers, it is also interesting to remark on two points. First, papers carried out in this field of science are increasingly co-authored

by a growing number of authors over time. Second, the high degree of collaboration between authors from different countries needed for their performance (one third of the papers sampled shows multinational co-authors). Both circumstances can be explained by the complexity of the problems associated with the use of water in agriculture, the analysis of which requires the collaboration of numerous groups of experts in order to provide the multidisciplinary and international approaches. This trend is also likely to be emphasised in the future, where most of the new knowledge will be generated through the cooperation of researchers with different scientific and geographical backgrounds.

With regard to the research methodology used, it is observed that almost all papers published in the period 2000-2009 are empirical studies developed using basic analysis approaches. This fact demonstrates that the economics of irrigation water is an applied field of science, aiming to solve real problems. This pragmatic vocation will remain during the forthcoming years, but it is probable that the complexity of the problems already mentioned will require a further sophistication in the methodology implemented. Thus, advanced mathematical programming techniques (dynamic, multicriteria or principal-agent models) and statistical analysis (econometric models) are likely to be considered in order to study the new challenges regarding irrigation water scarcity and quality problems.

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