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# BIBLIOMETRIC ANALYSIS OF MULTIPLE CRITERIA DECISION MAKING IN AGRICULTURE

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A b s t r a c t

Development trends (Research Trends) in scientific research on the methods of Multiple Criteria Decision Making (MCDM) and Multiple Criteria Decision Analysis (MCDA) in agriculture are analyzed. Established bibliometric techniques are applied. MCDA/MCDM methods are being very intensively developed in recent years, as evidenced by the number of scientific papers published annually in renowned scientific journals indexed in the Web of Science (WoS) database. In the years 1979–2015 a total of 1,355 scientific articles were collected in the database. The number of articles published annually increased rapidly after 2005. Besides, the annual number of citations of the publications is increasing. Research on MCDA/MCDM is conducted in many research areas. In the years 1984–2015 the Web of Science database accumulated 27 scientific publications on MCDA/MCDM in agriculture area. Therefore, it can be concluded that the MCDA/MCDM issues are currently not sufficiently analyzed in relation to agriculture. In the future this subject will probably be further developed, an increasing number of scientists will conduct research on the MCDA/MCDM and the annual number of articles published in the field will increase.

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## Introduction

Decision making is an integral part of human activity in all areas. Choosing the best option (optimal decision) is most often very difficult due to incomplete knowledge of the situation requiring a decision – a collection of all factors (dependent and independent of an evaluator), affecting the decision by the decision-maker in the decision-making process (KSIĄŻEK 2011). The most common decisions must be taken in conditions of uncertainty and taking into account many, often contradictory, criteria. Modeling a decision-making situation, one can differently assess importance of specific factors and aggregate variables. Solving such problems is the subject of the so-called multiple criteria decision analysis – MCDA (Multiple Criteria Decision Analysis). It is defined as a set of methods and mathematical tools to enable comparison of variants of decision, taking into account different and often conflicting criteria (PIWOWARSKI 2009, ŻAK 2014, KRUSZYŃSKI 2014). This area is also called multiple criteria decision making (MCDM – Multiple Criteria Decision Making).

It is considered that the beginning of the multiple criteria decision analysis (MCDA) was a scientific conference *Multiple Criteria Decision Making* organized by Cochrane and Zeleny in 1972 at Columbia University in South Carolina, USA (FIGUEIRA et al. 2005). Since then, there has been a rapid development of research on methods of multi-criteria decision analysis.

Decision making is closely related to a range of activities in agriculture. Owners of farms have to make decisions that are related to the organization of agricultural production, choice of technology, selection and operation of machinery and equipment, as well as the economics. Thus, providing the tools that allow to make the best decisions is an important task for scientists. As one of the tools are MCDA/MCDM methods, it is vital to determine the current state of research in applications of MCDA/MCDM in agriculture and to identify the development trends related to that research.

The aim of the paper was to analyse development trends (Research Trends) in scientific research on the methods of Multiple Criteria Decision Making (MCDM) and Multiple Criteria Decision Analysis (MCDA) in agriculture.

One way of attaining the objective is to use established bibliometric techniques. A bibliometric method was used in this research. An additional aim of this paper was to analyze the existing MCDA/MCDM methods and their classification.

## Classification of MCDA/MCDM methods

MCDA/MCDM methods are used to solve different kinds of decision-making problems. According to the criterion: the purpose of decision-making, multicriteria decision problems are divided into three (GRABAŃSKI 2015, KRUSZYŃSKI 2014) or four (PIWOWARSKI 2009, ROY 2005) groups:

– $P.\alpha$ – choice problematic – multi-criteria optimization – determining the best variant of the decision-making,

– $P.\beta$ – sorting problematic – the allocation of variants to specific categories,

– $P.\gamma$ – ranking problematic – ordering variants, classifying equally good variants,

– $P.\delta$ – description problematic – description of potential variants.

Due to the dynamic development of methods used to support decision makers in solving multi-criteria decision-making problems, there are difficulties in their unambiguous classification – different authors use different classification criteria. One of the most frequently cited is the classification of the methods into three groups (ŻAK 2014, KRUSZYŃSKI 2014, VINCKE 1992, SEIXEDO, TERESO 2010):

Group I – methods of Multi Attribute Utility Theory (MAUT), the so-called American school of multi-criteria decision support (B. Roy synthesis method to a single criterion, bypassing incomparability of the variants – e.g. UTA, AHP);

Group II – methods of outranking, so-called European / French / school of multi-criteria decision support (B. Roy methods of outranking synthesis, taking into account incomparability of the variants – e.g. ELECTRE I–IV, Promethee I, II and Oreste);

Group III – interactive methods or multi-objective mathematical programming models, (B. Roy dialogue methods of local assessment in different iterations – e.g. LBS STEM).

A similar classification of MCDA methods has been used in the book Multiple Criteria Decision Analysis: State Of The Art Surveys, edited by J. Figueiry, S. Greco and M. Ehrgott, published by Springer Publishing House (FIGUEIRA et al. 2005):

– Outranking Methods: ELECTRE Methods, PROMETHEE Methods, Other Outranking Approaches,

– methods based on Multiattribute Utility and Value Theories: UTA Methods, Analytic Hierarchy and Analytic Network Processes, MACBETH,

– Non-Classical MCDA Approaches.

A more extensive breakdown of methods of multi-criteria decision making (MCDM) is shown in Figure 1 (SOBCZYK et al. 2011, PIWOWARSKI 2009).

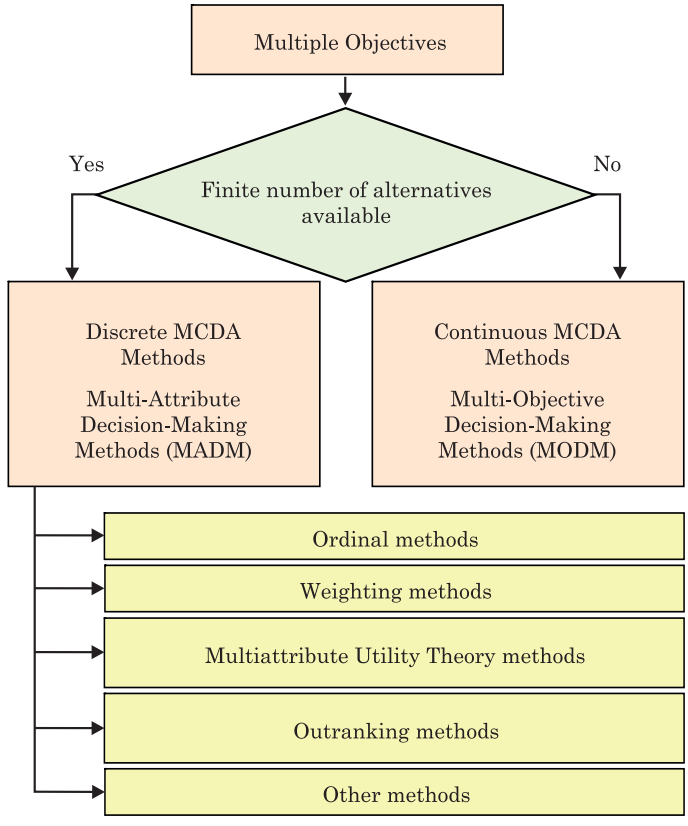


Fig. 1. Classification of multi-criteria decision support methods
Source: authors' own analysis based on PIWOWARSKI (2009), KODIKARA (2008), SOBCZYK et al. (2011)

PIWOWARSKI and KODIKARA divided discrete MCDA methods into five groups (PIWOWARSKI 2009, KODIKARA 2008, SOBCZYK et al. 2011) while Trzaskalik distinguishes seven groups of methods among the methods of decision support in multicriteria discrete decision-making (TRZASKALIK 2014a, TRZASKALIK 2014b):

– Additive Methods,
– The AHP method (Analytical Hierarchy Process) and related methods,
– Verbal Methods,
– ELECTRE Methods,
– PROMETHEE Methods,
– Use of reference points,
– Interactive Methods.

## Bibliometric method

**Bibliometry** was introduced by Pritchard in 1969 as a method of mathematical and statistical analysis applied to books and other communication media. Citation and content analyses are now widely used bibliometric techniques (SUN et al. 2012). Broadus defined bibliometry as a quantitative analysis of physically published units or bibliographic units (TSAI 2012).

Bibliometric research techniques are divided into evaluative and descriptive. Descriptive bibliometric techniques allow for the observation of trends in the development of science and technology, the identification of relevant actors on the stage of innovation and a better understanding of the specifics of individual areas of research (KLINCEWICZ et al. 2012).

Bibliometric techniques have many advantages. The most important is the ability to conduct quantitative analyses objectified based on the codified knowledge – measurable, objectified, consistent and accessible data, HICKS et al. (2002). Hence, bibliometrics is an effective and important tool to determine the trends of research in various fields of science (AKHAVAN et al. 2016, ELLEGAARD, WALLIN 2015, KADEMANI et al. 2013, KUMARI 2013, PENG et al. 2015, YANG et al. 2013, SUN et al. 2012).

As confirmed by some publications (KLINCEWICZ et al. 2012, ELLEGAARD, WALLIN 2015), research institutions, universities as well as individual scientists are interested in systematic observation of technological development and research trends.

The results of bibliometric analyses are now often used, particularly in the areas of basic and applied sciences (ELLEGAARD, WALLIN 2015).

Analyses of publications were conducted, among others, and trends set in the areas of scientific research in relation to:

– knowledge management (AKHAVAN et al. 2016),
– materials science (KADEMANI et al. 2013),
– synthetic organic chemistry (KUMARI 2013),
– digital elevation model – DEM (PENG et al. 2015),
– engineering (UCAR et al. 2014),
– solid waste (YANG et al. 2013).

Bibliometrics can be successfully used to determine trends in the field of agriculture and forestry (KLINCEWICZ et al. 2012).

Bibliometric analysis requires the selection of a database, on the basis of which publications will be obtained. One of the most widely used databases for bibliometric analysis of publications in the Web of Science (WoS), which contains articles with the highest level of quality – from magazines with a significant impact factor (AKHAVAN et al. 2016, ELLEGAARD, WALLIN 2015, HU et al. 2010, KADEMANI et al. 2013, PENG et al. 2015, SUN et al. 2012, TSAI 2012,

YANG et al. 2013). Therefore, in this study the WoS database has been used as a data source.

Bibliometric analyses usually take place in several stages (SUN et al. 2012, TSAI 2012, VAN RAAN, VAN LEEUWEN 2002, YANG et al. 2013):

1. The assembly of data on publications (complying with adopted criteria) indexed in the selected database and creating a set of publications;

2. Classification of publications collected on the basis of search (included in the collection of publications) in terms of:

– document type,

– the characteristics of publications in different years,

– the characteristics of citations of publications in those years,

– country / territory from which the authors of the publication come,

– dominant institutions in which the research was carried out, on the basis of affiliation of the authors of the publications,

– the most important magazines in which publications were issued,

– authors with the greatest number of published articles and the highest number of citations;

3. Analysis of the results of classification.

## Materials and Methods

As part of this paper a set of publications was created on the basis of search in the Web of Science Core Collection database, on the subject of articles terms: "Multiple Criteria Decision Analysis" or "Multiple Criteria Decision Making". The search was performed on documents in English from 1945 until 2015.

After determining the number of document types, further analyses were carried out for the identified scientific publications (Document Types: Article). The distribution in time for a number of scientific publications and the number of citations of these publications in the years 1979–2015 was made. The main "Research Areas" were identified, as well as main "Web of Science Categories", "Countries/Territories" the authors of the publication came from, scientific institutions the authors are affiliated with (Organizations) and the authors who have published the largest number of articles.

Then, the subset in the Research Area: Agriculture was separated from the accumulated set of publication. For those publications we determined:

– distribution of the number of scientific publications in time and the number of citations of those publications,

– the major categories of the Web of Science,

– country / state the authors of the publications came from,

– research institutions the authors are affiliated with and the authors who have published the largest number of articles.

## Results

As a result of the search in the Web of Science Core Collection (topic: Multiple Criteria Decision Analysis or Multiple Criteria Decision Making; the period from 1945 to 2015) 2021 records/documents were identified. Among the documents found, articles were the most numerous – 1355, followed by proceedings papers – 663. Other documents include: books reviews – 35, publication reviews – 34, meeting abstracts – 11, notes – 5 books – 4, letters – 2 and discussions – 1. The first publication appeared in 1979.

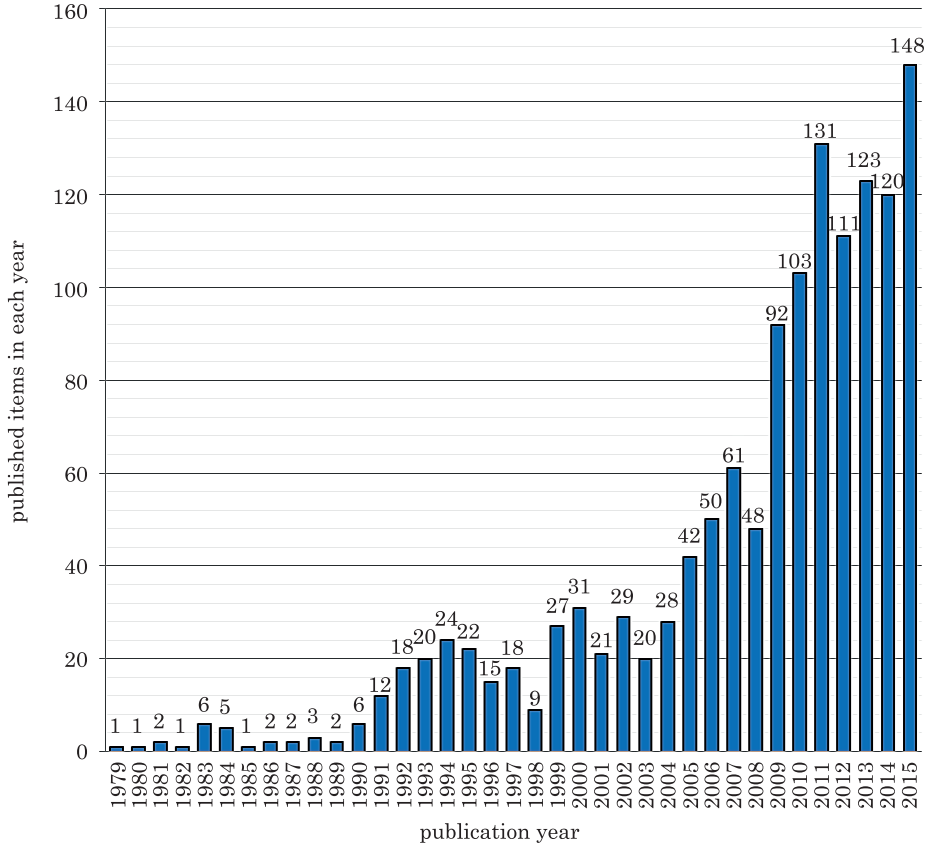


Fig. 2. The number of scientific articles indexed in the Web of Science Core Collection database, published in different years

Analysing the change in the number of scientific articles published in different years (Fig. 2) is it possible to distinguish four periods:

I from 1979 to 1990 – the average number of publications 2.7.

II from 1991 to 2004 – the average number of publications 21.0.

III from 2005 to 2009 – the average number of publications 58.6.

IV from 2010 to 2015 – the average number of publications 122.7.

The importance of the multi-criteria decision analysis (Multiple Criteria Decision Analysis) or multi-criteria decision-making (Multiple Criteria Decision Making) is evidenced not only by the number of scientific publications but also by the number of citations of these publications in the Web of Science Core Collection database (WoS-CC). In the years 1981 to 2015 the total number of citations was more than 23,000 (23,167). The number has been rising very sharply since 2005 (Fig. 3).

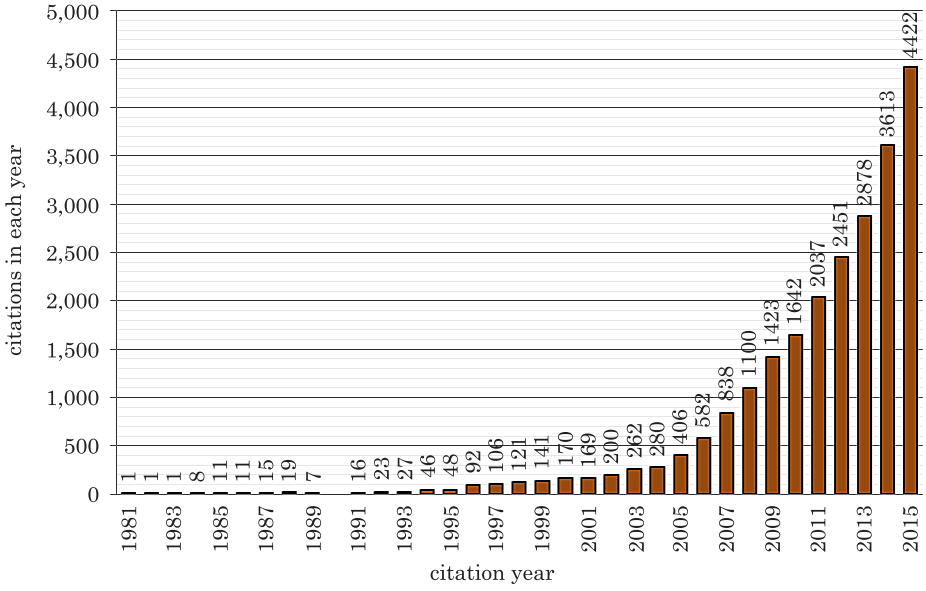


Fig. 3. The number of citations of scientific articles found in the Web of Science Core Collection database in different years

The most frequently cited publication (Tab. 1) had 603 citations (to year 2015) and the average number of citations during the year amounted to more than 50.

The accumulated set of 1,335 publications included 62 research areas, with most publications in the area of: Computer Science – 512, Operations Research And Management Science – 510, Engineering – 424 and Business Economics – 329.

A similar range is related to the use of Web of Science Categories. Most of the publications belonged to the categories: operational research and management science – 519, computer science artificial intelligence – 312, Management – 239 and Computer Science Interdisciplinary Applications – 157.

Table 1

The most cited publications on MCDA/MCDM in the years 1981–2015

| Authors | Title | Publication year | Journal | TC | AvC |
|---|---|---|---|---|---|
| Opricovic S., Tzeng G.H. | *Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS.* | 2004 | European Journal of Operational Research, 156(2): 445–455 | 603 | 50.3 |
| Chen C.T., Lin C.T., Huang S.F. | *A fuzzy approach for supplier evaluation and selection in supply chain management. By:.* | 2006 | International Journal of Production Economics, 102(2): 289–301 | 411 | 41.1 |
| Tzeng G.H., Chiang C.H., Li C.W. | *Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL.* | 2007 | Expert Systems With Applications, 32(4): 1028–1044 | 252 | 28.0 |

TC – total number of citations
AvC – average number of citations per year

In the analyzed set of publications the most frequently published were authors from Taiwan (294) USA (229) and the People's Republic of China (150). Polish authors had 38 publications.

Most of the publications were affiliated to the National Chiao Tung University, Hsinchu, Taiwan – 66, Kainan University, Taoyuan, Taiwan – 57, Vilnius Gediminas Technical University, Vilnius, Lithuania – 45. As regards the Polish scientific institutions, most of the publications were affiliated to the Polish Academy of Science, Warsaw, Poland – 13, the Poznan University of Technology, Poznan, Poland – 11 and Technical University Czestochowa, Czestochowa, Poland – 8.

The author of the most numerous publications is TZENG Gwo-Hshiung (Graduate Institute of Urban Planning, National Taipei University, New Taipei City & Institute of Management of Technology, National Chiao Tung University, Hsinchu, Taiwan) – 59. Slightly lower results are achieved by: CHEN Ting-Yu (Department of Industrial and Business Management, Graduate Institute of Business and Management, College of Management, Chang Gung University, Taiwan) – (31) ZAVADSKAS Edmundas Kazimieras (Department of Construction Technology and Management, Vilnius Gediminas Technical University, Vilnius, Lithuania) – 24 and Carlos ROMERO (Department of Forest Economics and Management, Forestry School, Technical University of Madrid, Madrid, Spain) – 23. Among Polish authors, with the best results are achieved by: KALISZEWSKI Ignatius (Systems Research Institute, Polish Academy of Science, Warsaw, Poland) and SLOWINSKI

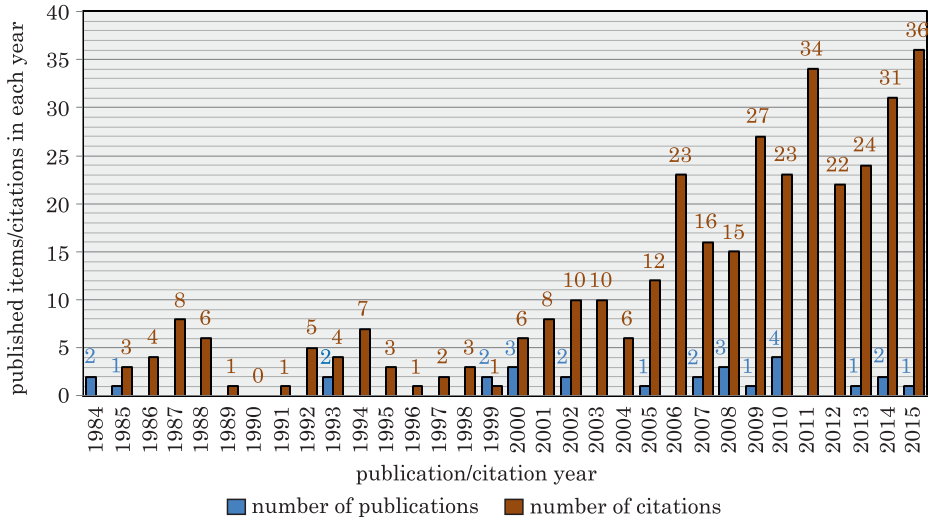


Fig. 4. The number of publications and citations in the Research Area Agriculture

Roman (Institute of Computing Science, Poznan University of Technology, Poznan & Systems Research Institute, Polish Academy of Science, Warsaw, Poland) – 8 publications each.

A subset of publications in the Research Area: AGRICULTURE has 27 scientific articles. The first two publications appeared in 1984. After analysing the change in the number of scientific articles published in different years (Fig. 4), two periods can be distinguished:

I from 1984 to 1998 – the average number of publications 0.3 (5 publications),

II from 1999 to 2015 – the average number of publications 1.3 (22 publications).

Between 1985 and 2015 the total number of citations was 352, while the number of citations in a year has clearly increased since 2005. The most cited publication (Tab. 2) had 46 citations (to year 2015) and the average number of citations per year was 4.2.

The analyzed subset of the publication is contained mainly in such WoS (Web of Science Categories) categories as Agriculture Multidisciplinary – 14, Agricultural Economics Policy – 6, Economics – 4, Agricultural Engineering – 3 and Computer Science Interdisciplinary Applications – 3.

In the analyzed subset of publications, the most widely published authors came from England (6), Spain (6) United States (4) Iran (3) and the Netherlands (3).

Most publications were affiliated with (University Of Reading, Reading, UK) – 6 (Universidad De Cordoba) – 4 (Wageningen University Research

Table 2
The most cited publications on MCDA/MCDM in the Research Area Agriculture in the years 1984-2015

| Authors | Title | Publication year | Journal | TC | AvC |
|---|---|---|---|---|---|
| Gilliams S., Raymaekers D., Muys B., Van Orshoven J. | *Comparing multiple criteria decision methods to extend a geographical information system on afforestation* | 2005 | Computers and Electronics in Agriculture, 49(1): 142–158 | 46 | 4.3 |
| Rehman T., Romero C. | *The application of the MCDM paradigm to the management of agricultural systems – some basic considerations* | 1993 | Agricultural Systems, 41(3): 239–255 | 42 | 1.8 |
| Romero C., Rehman T. | *Goal programming and Multiple Criteria Decision – Making in farm-planning an expository analysis* | 1984 | Journal of Agricultural Economics, 35(2): 177–190 | 31 | 1.0 |
| Rehman T., Romero C. | *Multiple – Criteria Decision-Making techniques and their role in livestock ration formulation* | 1984 | Agricultural Systems, 15(1): 23–49 | 30 | 0.9 |

TC – total number of citations
AvC – average number of citations per year

Center) – 3 (Polytechnic University Of Madrid) – 2 and (University of Tehran) – 2.

The authors of the largest number of publications in the analyzed subset are REHMAN Tahir (Department of Agriculture, University of Reading, Reading, UK) – 6 publications and ROMERO Carlos (Department of Forest Economics and Management, Forestry School, Technical University of Madrid, Madrid, Spain) – 5 publication.

Poland is represented only by 1 publication. Its co-author was Piech Bozena (Department of Economics, Organization & Management, Agricultural Academy of Szczecin, Szczecin, Poland): Piech B; Rehman T. 1993. *Application of multiple criteria decision-making methods to farm-planning – A case-study*. Agricultural Systems, 41(3): 305–319.

Most of the publications from the analyzed subset were published in the following journals: Agricultural Systems (6), Computers And Electronics In Agriculture (3) and the Journal Of Agricultural Economics (2).

## Conclusions

Summing up the results, it can be concluded that:

Up to now very large number of MCDA/MCDM methods have been designed and new ones are constantly being developed. This causes problems because the classification of the methods has not been harmonized and different authors offer different classifications.

MCDA/MCDM methods are being very intensively developed in recent years, as evidenced by the number of scientific papers published annually in renowned scientific journals indexed in the Web of Science database. In the years 1979–2015 a total of 1,355 scientific articles was collected in the WoS database. A rapid increase in the number of articles published during the year started after 2005. In 2015 there were 148 publications on methods of MCDA/MCDM the Web of Science database. Besides, the annual number of citations of the publications is increasing.

Research on MCDA/MCDM is conducted in many research areas. A set of 1,335 publications gathered from Web of Science resources consisted of 62 Research Areas, with most of the publications in the area of: information technology (Computer Science) – 512 and operations research and management science (Operations Management Science Research) – 510.

MCDA/MCDM methods are also the subject of research in the field of agriculture (Research Areas: Agriculture). However, until 2015 the Web of Science database accumulated only 27 scientific publications on MCDA/MCDM in this field, which accounts for just 2% of the total articles focused on MCDA/MCDM methods (1,355 articles). Therefore, we can conclude that research on MCDA/MCDM methods in agriculture is not widely performed, despite the presence of many decision-making problems. This can be explained by the fact that new methods of decision support are developed mainly in the area of operations research and management science. In the next stage, they are disseminated in the area of information technology. Therefore, application of new methods for decision support in agriculture is delayed. Another reason for the low level of interest in those methods may also be the nature of decision-making in agricultural production, namely, decisions are usually made by a single person. As a result, decisions are taken on basis of experience and less complex computational methods.

We can, however, expect that with the development of information technology, universal access to computers and user-friendly computer programs, the application of computationally complex methods will gradually become more and more wide-spread. The increase in the number of citations that can be observed since the year 2000 seems to confirm a growing interest in scientific methods MCDA/MCDM for agriculture.

It can be assumed that in the future this subject will be developed, an increasing number of scientists will conduct research on the MCDA/MCDM and the number of articles published during the year will increase.

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