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Operations Research Problems and Data Envelopment Analysis in Agricultural Land Processing – A Review

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Abstract:

Research Question: This paper aims at specifying the contribution of operations research (OR) methods and techniques to agricultural land processing. **Motivation:** Agricultural production is performed on an agricultural land, which has to be exploited in the best possible way, given the increasing human population and the limited availability of the land. Considering the importance of this issue, a large number of research studies dealing with problems in agriculture can be found in the literature, and many of these problems are solved by OR methods and techniques. However, to our knowledge, there are no review papers that deal with this specific area, so the main motivation is to provide a detailed review of selected OR methods application in the agricultural land processing area. **Idea:** The core idea behind this research is to perceive a real impact of OR methods and techniques implementation in the agricultural land processing. The research is based on detailed literature review for the period 2014-2019 and performed statistics involving publication by year, publication by journal and statistics involving keywords in articles. **Data:** The review was conducted using online repositories of the papers published in SCI and SCIe journals with impact factors in the period from 2014-2019. **Tools:** Analyzed papers are divided into three groups according to the OR method applied: linear optimization problems, DEA method and other OR methods (non linear, multicriteria, mixed integer programming, dynamic programming). Papers within the groups are analyzed according to the type of problems solved. Statistical analyses of all collected data were used to get a good insight into the applications of operations research problems and data envelopment analysis in agricultural land processing. **Findings:** The number of published papers in this specific area has a growing trend over the observed years (with some minor decrease in 2016 and 2019 in comparison with the previous year). All of the articles are related to specific application of the given methods to solving problems in the agricultural land processing, and this is the reason for many different keywords appearing in the articles. Some very important keywords such as “operations research” or “OR” does not appear in any article as a keyword. Inclusion of such common keywords may result in a faster search in repositories of all articles. **Contribution:** The primary contribution of this paper is a detailed review of application of linear optimization, data envelopment analysis and other OR methods in agricultural land processing in the period 2014-2019.

Keywords: Agriculture, processing of agricultural land, data envelopment analysis (DEA), operations research, OR methods

JEL Classification: Q15, C44, C67

1. Introduction

The growth of human population and industrial production consequently leads to increased pollution, land degradation, habitat fragmentation and unsustainable consumption, and due to extensive use, arable land is of poorer quality, getting more and more polluted, and consequently the availability is reduced. Effective agriculture management is necessary to maximize land productivity at this moment and in the future (Andric Gusavac & Savic, 2019).

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Agricultural problems can be solved by various operations research methods and these methods have helped over the past decades to understand the complex functioning of agricultural systems, as well as to manage these systems in an efficient way (Weintraub & Romero, 2006).

Problems related to the agricultural land processing are very common in the literature. Problems related to the: crop diversification, crop planning and crop rotation are solved. Decisions are made regarding the type of crops to be grown in the planning horizon (plant different crop in each or every couple of periods). Problems of this kind are often modelled by linear programming and mixed linear programming (Boboev, Djanibekov, Bekchanov, Lamers & Toderich, 2019; Albornoz, Nanco & Saez, 2019; Aljanabi, Mays & Fox, 2018). Problems in choosing farmland / tillage strategies at farm level to avoid soil degradation are also modelled by linear (Boboev et al., 2019). and mixed linear programming (Bavorova, Imamverdiyev & Ponkina, 2018). For all these types of problems, the area where the land is located - arid or not, the availability of irrigation water, the availability of energy and all other resources, etc., is taken as the decision factor. Regarding the problems of efficiency and technical efficiency of agriculture, the DEA method is applied (Muhtarom, Haryanto & Istifadah, 2019; Li, Jiang, Mu & Yu, 2018).

A review of the literature in the last five years reveals that the most common problems in the field of agriculture, which are solved by operations research methods and techniques, are related to the processing of agricultural land. Papers published in SCI and SCIe journals according to KOBSON (Kobson, 2019) are presented in this paper. The number of papers dealing with the implementation of operational research in the field of agriculture in the last five years is more than 80, and they are modelled by linear, nonlinear, mixed integer programming, dynamic programming, multi-criteria models and Data Envelopment Analysis (DEA). A very large number of problems is successfully modelled by linear programming (LP), and these papers are presented in the third chapter of this paper. The DEA method is widely used for efficiency assessment in the agricultural chapter, and 21 papers regarding agricultural land related problems solved by DEA method are presented in chapter 4. Agricultural land processing problems solved by other operations research (OR) methods and techniques are presented in chapter 5 of this paper.

The next section provides a series of selected statistics involving the articles and journals within our literature review.

2. Publication Statistics

2.1. Statistics involving publications by year

Fig. 1 shows the distribution of OR articles in agricultural land processing published by year.

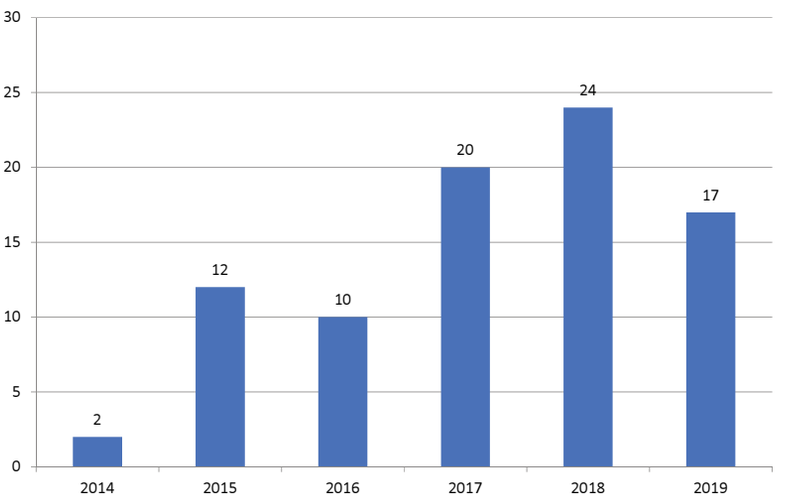

Figure 1: Distribution of agricultural land processing articles by year

Note that the number of papers is growing over the years, with some minor decrease in 2016 and 2019.

2.2. Statistics involving publications by journal

Table 1 lists 13 journals that have published the largest number of OR and agriculture related papers in the past 5 years. Journals such as Computers and Electronics in Agriculture, Land Use Policy, Sustainability (Switzerland) and Agricultural Systems are the most utilized journals. The scope of these journals falls within the fields of operations research and management science combined with agriculture, so these results are expected.

Table 1: Journals that have published the greatest number of agricultural land processing articles

No.	Journal	Number of articles	% of articles
1	Computers and Electronics in Agriculture	10	11.76
2	Land Use Policy	6	7.06
3	Sustainability (Switzerland)	6	7.06
4	Agricultural Systems	5	5.88
5	Agricultural Economics (Czech Republic)	4	4.71
6	Journal of Cleaner Production	4	4.71
7	Journal of Environmental Management	3	3.53
8	Journal of Irrigation and Drainage Engineering	3	3.53
9	Energy	2	2.35
10	Environment, Development and Sustainability	2	2.35
11	Environmental Science and Pollution Research	2	2.35
12	Pakistan Journal of Agricultural Sciences	2	2.35
13	Other journals (36 journals)	1 (36)	1.18 (42.35)
Total		85	100

2.3. Statistics involving keywords used in articles

Regarding the papers of linear optimization problems in agricultural land processing, a total of 165 keywords are detected (average of 5.89 keywords per article). Most commonly utilized keywords in this area are listed in table 2. Only keywords that appear 3 or more times are listed.

Table 2: Keywords commonly used in LP/Agricultural land processing articles

No.	Journal	No. of articles
1	Crop (crop rotation, crop production, crop planning, crop residues, crop diversification)	13
2	Linear programming	8
3	Environmental impact	5
4	MILP	5
5	Conjunctive use	3
6	Harvest	3
7	Optimisation	3
8	Precision agriculture	3

Although all of these articles are contributions of OR methods and techniques in specific area (agricultural land production), the keyword "operations research in agriculture" appears only in one article.

Most commonly used keywords in DEA applications in agricultural land processing are listed in table 3. A total of 122 keywords are detected in this area (average of 4.88 keywords per article). Only the keywords that appear 3 or more times are listed.

Table 3: Keywords commonly used in LP/Agricultural land processing articles

No.	Journal	No. of articles
1	Data envelopment analysis	13
2	Agriculture	8
3	Technical efficiency	5
4	Eco-efficiency	5
5	Sustainability	3
6	Energy use efficiency	3

When we list the keywords used in OR methods (beside LP and DEA), we can notice (table 4) that here we have more matching keywords than in LP and DEA applications. Like in previous cases, only the keywords that appear 3 or more times are listed. Most commonly used keywords are “agriculture”, “multi criteria analysis” and “optimisation”. A total of 236 keywords are detected in this area (average of 6.74 keywords per article).

Table 4: Keywords commonly used in DEA/Agricultural land processing articles

No.	Journal	No. of articles
1	Data envelopment analysis	13
2	Agriculture	8
3	Technical efficiency	5
4	Eco-efficiency	5
5	Sustainability	3
6	Energy use efficiency	3

3. Overview of Linear Optimization Problems in Agricultural Land Processing

Operations research methods and techniques are extensively applied to solve problems in the field of agriculture. Modelling, as a basic tool in the science of agricultural systems, has been developed by scientists working in various fields over the past six decades (Jones et al., 2017).
Table 5 shows the papers dealing with problems related to agricultural land processing, which are solved by linear programming. A brief description of the problem and a formulated model for solving the problem is given for each paper.

Table 5: Overview of linear optimization problems in agricultural land processing (adapted from Andric Gusavac & Savic, 2019)

No.	Journal	No. of articles
1	Data envelopment analysis	13
2	Agriculture	8
3	Technical efficiency	5
4	Eco-efficiency	5
5	Sustainability	3
6	Energy use efficiency	3

Many of the agricultural problems modelled as linear programming problem are solved by exact methods (Cid-Garcia & Ibarra-Rojas, 2019; Ahodo et al., 2019; Boboev et al., 2019; Kiryluk-Dryjska & Beba, 2018; Smith et al., 2018; Bavorova et al., 2018; Zhang et al., 2017; Singh, 2017; Capitanescu et al., 2017; Pieralli, 2017; Nidumolu et al., 2016; Rocco & Morabito, 2016; Galan-Martin et al., 2015; Naudin et al., 2015; Das et al., 2015; Singh, 2015).

Problems related to the processing of agricultural land are very common in the literature: division of arable land, crop planning, and crop rotation are solved. Crop rotation and crop planning are type of problems that are solved by linear programming in 13 analysed articles (48,15%). Problems of division of arable land and resource planning include 22.22% (11.11% of articles each), and two articles (7.41%) deal with harvesting problems; the same number of articles is for conversion of land or conversion of agriculture production (Fig. 2).

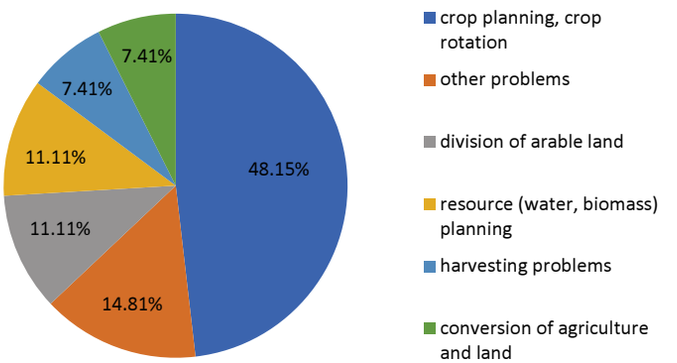

Figure 2: Distribution of agricultural problem types solved by LP

4. Overview of DEA Problems in Agricultural Land Processing

The most commonly used technique for the problems of evaluation and comparative analysis of efficiency in agriculture is the mathematical programming technique - Data Envelopment Analysis (DEA) (Charnes, Cooper & Rhodes, 1978).

Papers dealing with the problems of evaluation and comparative analysis of agricultural efficiency are shown in Table 6. For each reference a brief description of the problem is given.

Table 6: Overview of DEA problems in agricultural land processing (adapted from Andric Gusavac & Savic, 2019)

Reference	Problem	Model
Masuda, 2019	expanding the size of rice farms and impact on eco-efficiency of rice production	DEA and LCA (life cycle assessment)
Djokic, Jurjevic, Popovic & Savic, 2019	comparison of organic and conventional soybean production systems	DEA
Guth & Smędzik-Ambroży, 2019	technical efficiency of different types of agricultural production	DEA
Grados & Schrevens, 2019	assessment of the environmental impact of potato production and assessment of the eco-efficiency of agricultural systems	DEA
Muhtarom et al., 2019	efficiency and productivity analysis of the agricultural production	DEA
Rybaczewska-Błazejowska & Gierulski, 2018	assessment of th eco-efficiency of the agricultural production in EU	DEA
Li et al., 2018	technical efficiency evaluation and energy savings potential in China agricultural sector	DEA
Khoshroo, Izadikhah & Emrouznejad, 2018	energy efficiency of the turnip production and reduction of CO_2 emission	DEA
Moutinho, Madaleno, Macedo, Robaina & Marques, 2018	efficiency of the European agricultural sector	DEA
Masuda, 2018	energy efficiency of intensive rice production in Japan	DEA
Staniszewski, 2018	assessing sustainable agriculture intensification in the European Union	DEA
Abbas et al., 2018	new approach for energy efficiency assessment and sustainability of wheat production	DEA
Godoy-Durán, Galdeano- Gómez, Pérez-Mesa & Piedra-Muñoz, 2017	eco-efficiency assessment of small farms engaged in horticulture	DEA
Khanjarpanah, Pishvaee & Seyedhosseini, 2017	evaluation the candidate locations efficiency for switchgrass cultivation used for biofuel production	risk averse cross-efficiency DEA model
Toma, Miglietta, Zurlini, Valente & Petrosillo, 2017	evaluation of agricultural efficiency in European Union	bootstrap-DEA
Vlontzos, Niavis & Pardalos, 2017	assessment of the sustainability of the agricultural sector using the eco-efficiency index	DEA
Pokhrel & Soni, 2017	analysis of the energy, environmental and financial performances of different rice-based cropping systems	DEA
Murtaza & Thapa, 2017	assessment of the technical efficiency in apple production sector	DEA
Atici & Podinovski, 2015	evaluation of the efficiency of units of different specialization in the agricultural sector	DEA
Gadanakis, Bennett, Park & Areal, 2015	assess sustainable intensification at a farm level (identification of appropriate production technologies and practices)	DEA
Nowak, Kijek & Domańska, 2015	measurement of the technical efficiency of agriculture in the European Union countries	DEA
Kocisova, 2015	measurement of the relative technical efficiency of agriculture in the European Union	DEA
Souza & Gomes, 2015	assessment of the economic efficiency of agriculture	DEA
Mirza, Najam, Mehdi & Ahmad, 2015	evaluation of technical efficiency of wheat farms	DEA

It is interesting to distinguish different types of efficiency determined by the DEA method in the agricultural land processing area. This distribution is presented in Fig. 3.

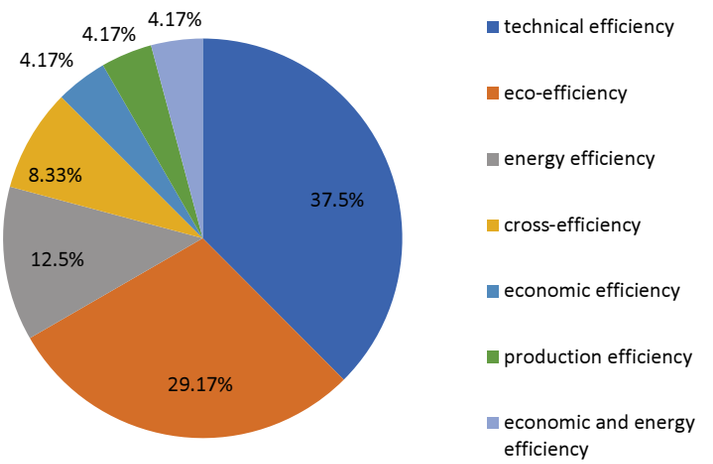

Figure 3: Distribution of efficiency type solved by DEA method

Nine papers presented in table 6 examine the technical efficiency (9 out of 24) and seven papers examine the eco-efficiency (7 out of 24). These two types of efficiency measures are the most common efficiency measures that are solved in published papers in the agricultural land processing area. Other types of efficiency measures (energy, cross-efficiency, economic, production and some combinations) are represented in 33.33% (8 papers out of 24).

5. Overview of Other OR Methods Used in Agricultural Land Processing

Agricultural problems are often very complex and could only be modelled by non linear programming. They also include more than one criterion, so the multi objective optimization is used for these problems.

Table 7: Overview of other OR methods in agricultural land processing

Reference	Problem	Model
Luqman, Saeed, Ali, Tabassam & Mahmood, 2019	crop rotation in organic farming	linear and nonlinear programming
West, 2019	crop rotation problem in horticulture	multicriteria optimization
Utamima, Reiners & Ansaripoor, 2019	agricultural routing planning	binary integer programing model
Boyabatli, Nasiry & Zhou, 2019	allocation of farmland among multiple crops in each growing season	dynamic programming
Andric Gusavac, Stanojevic & Cangalovic, 2019	agricultural land treatment using aviation	mixed integer mathematical programming model
Carvajal, Sarache & Costa, 2019	crop planning; strategic and tactical planning in sugarcane supply chain	linear programming, stochastic optimization
Udias et al., 2018	increase agricultural growth by identification and selection of optimal agricultural strategies	multiobjective optimization
Dunnett et al., 2018	land use allocation in order to prioritize agriculture interventions	multiobjective optimization
Aljanabi et al. 2018	crop planning and allocation of waste water	mixed-integer nonlinear programming
Vasu et al., 2018	identification of soil characteristics and assessment of the suitability of the soil for crop planting	multicriteria evaluation of land suitability

Reference	Problem	Model
Talukder, Hipel & van Loon, 2018	assessment of the sustainability of agricultural systems	multi-criteria decision analysis
Iocola et al., 2018	assessment of the sustainability of organic vegetable production	multi criteria analysis
Musakwa, 2018	identification of land suitable for implementation of agricultural reforms	geo-information systems, multi-criteria decision analysis
Qureshi, Singh & Hasan, 2018	crop planning for sustainable agricultural production	fuzzy multicriteria decision making
Ma, Zhang, Ma, Fan & Zhao, 2018	production and operation scheduling in wheat harvesting operation	dynamic programming
Nuppenau, 2018	crop rotation problem	dynamic programming
Kung, 2018	sustainable development of agriculture framework	dynamic programming
Cobo, Dominguez-Ramos & Irabien, 2018	development of system efficiency indicators in extending the lifetime of organic waste	multiobjective mixed integer linear programming model
Mosleh et al., 2017	crop planning on suitable cultivable lands, allocation of arable land and water resources	goal programming model
Priya & Geetha, 2017	optimization of agricultural resources (water, fertilizer, micronutrients) for plant growing	dynamic programming, dynamic resource minimization algorithm
Afzal, Naeem, Iqbal, Sharif & Huang, 2017	allocation of energy resources in agricultural production	integer programming model
Srivastava & Singh, 2017	allocation of agricultural land to crops	fuzzy multiobjective-based goal programming model
Filippi, Mansini & Stevanato, 2017	crop mix selection	mixed integer linear programming, conditional Value-at-Risk
Galan-Martín, Vaskan, Antón, Esteller & Guillén-Gosálbez, 2017	crops planning; allocation of rainfed and irrigated arable land	multiobjective linear programming model
Talukder, Blay-Palmer, Hipel & van Loon, 2017	assessment of sustainability of different agricultural systems	multicriteria decision analysis
Jana, Sharma & Chakraborty, 2016	agricultural production planning	fuzzy goal programming
Bueno-Delgado, Molina-Martínez, Correoso-Campillo & Pavón-Mariño, 2016	Android application for the problem of fertilizer selection for agricultural production	linear programming
Singh et al., 2016	review; allocation of groundwater and surface-water resources for irrigation	linear programming, nonlinear programming, dynamic programming, and genetic algorithms
St John et al., 2016	designing a deer migration corridor with harvest planning	mixed integer programming; spatial optimization
Montgomery, Dragicevic, Dujmovic & Schmidt, 2016	evaluation of the capability and suitability of land for agricultural production	geo-information systems, soft computing
Cabrini & Calcaterra, 2016	land allocation to crops: evaluation of the economic and environmental impacts	compromise programming
Diban et al., 2016	optimization of biomass plantation replanting policy	dynamic programming
Alfandari, Plateau & Schepler, 2015	sustainable crop rotation planning	integer programming
Baglivi, Fiorese, Guariso & Uggè, 2015	allocation of agricultural land to crops	multiobjective nonlinear programming

It is interesting to see agricultural problem types that are solved by OR methods other than LP and compare these types with problem types solved by LP (presented in Figure 2). Problems related to the processing of agricultural land solved presented in Table 7 can be grouped into seven categories: crop planning, crop rotation, other problems, sustainability and sustainable development in agriculture area, resource (energy, water, biomass) planning, harvesting problems, allocation of agricultural land, routing problem in agriculture. Distribution of these groups can be seen in Figure 4.

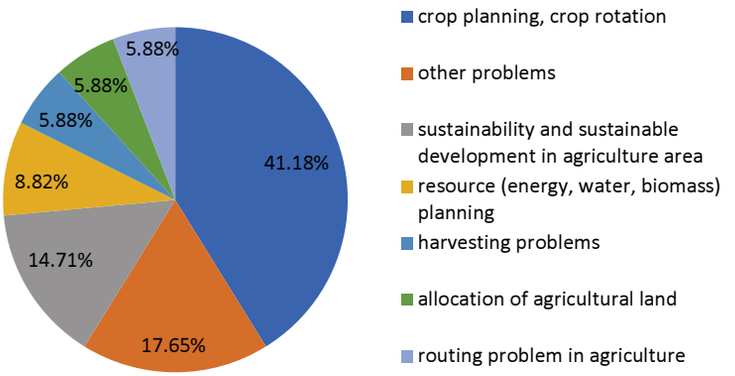

Figure 4 Distribution of agricultural problem types solved by other OR methods

Most of the analysed articles are dealing with crop planning and crop rotation problems (41.18%). This is a very similar percentage as in LP solved problems shown in Figure 2. Harvesting problems and resource problems are also solved by LP (harvesting 7.41%, resource 11.11%) and other OR methods (harvesting 5.88%, resource 8.82%).

Conslusion

The problems of agricultural land cultivation are successfully solved by the methods and techniques of operational research, and this paper gives an overview of problems solved by OR methods and techniques. It can be concluded that a large number of problems can be solved by linear programming, which is good, because these problems of large dimensions can be solved exactly, and the problems that occur in agriculture are always large-scale problems.

The papers included in a literature review cover the period of the last five years. The basic idea for this paper is to perceive a real impact of operations research methods and techniques implementation in the agricultural land processing. According to the above conducted analysis of the literature in this area, a total of 85 published articles are divided into three groups. The groups are formed according to methods used in modelling the problem. We perceived two groups: application of linear programming (27 articles) and application of DEA method (24 articles) in solving the agricultural land processing problems. Other OR methods applications (34 articles) are joined in the third group.

It is interesting that all of the articles (except Singh et al., 2016) are related to the application of the given methods to solving the agricultural land processing problems. Applications are very specific and this is the reason we have so many different keywords appearing in the articles. We noticed that “operations research” or “OR” does not appear in any article as a keyword, only "OR in agriculture" appears in two articles (Albornoz et al., 2019, Alfandari et al., 2015). The inclusion of such common keyword may result in afaster search in repositories of all articles.

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