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OPTIMAL MODEL FOR AN AGRICULTURAL COMPANY THAT OPERATES SEVERAL FARMS

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Abstract. *This paper presents an optimal model for an agricultural company that operates several farms to obtain the maximum utility taking into account the constraints following: 1) land availability for each of the farms; 2) water availability for each of the farms; 3) land availability for each of the farms by each crop; 4) equal percentage of land available (proportional) for each crop. Numerical examples for an agricultural company that operates four farms are shown through two cases. Case 1 takes into account the first three constraints. Case 2 considers all the constraints. The maximum utility is presented for the case 1 that does not consider the constraint of an equal percentage of land available (proportional) for each crop. The optimization techniques will significantly improve the total utility with optimal area allocation cultivated to each crop in each farm.*
Keywords: Optimal model, Agricultural company, Farms, Maximum utility

1. **Introduction.** Optimization is a commonly used approach to solving problems of production planning in the sense of optimal resource allocation given the changing conditions that farms face.

The optimization of the product range as a part of the marketing complex shall be grounded on identifying general trends in this field, determining its optimal parameters based on economic and mathematical modeling.

The dynamic circumstances in which farmers operate lead to considerable complexity in the decision making process. Questions like, how to organize production plan to achieve better results or economic efficient production are common issues in farm management. Both agricultural enterprises and individual farm households make simultaneous management decisions concerning production, procurement, marketing and finances.

The study of farm management involves three successive stages:

1) analysis of the present position of the farm business;

2) interpretation of the present position for indication of possible improvements;

3) preparation of an acceptable course of action for improvement of performance of the farm business.

The most relevant papers addressing the issue of agriculture optimization are shown as follows.

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Sumpsi et al. analyzed and used a multi-criteria methodology aimed at researching the objectives actually followed by a farmer or by a homogeneous group of farmers to predict the behaviour of family farms in “Vega de Córdoba” (Spain). The proposed methodology has an algorithmic structure and is articulated within a goal programming formulation [1].

Amador et al. proposed a methodological approach for eliciting farmer’s utility functions. The methodology is non-interactive, in that the parameters defining the utility function are obtained by observing the actual behavior adopted by farmers without resorting to the use of questions on random lotteries [2].

Kurytskyy saw the economic mathematical model as a concentrated expression of the most significant relationships and regularities of the economic system functioning process in mathematical form [3].

Biswas and Pal used the fuzzy goal programming efficiently for modeling and solving land-use planning problems in agricultural systems for optimal production of several seasonal crops in a planning year [4].

Žgajnar et al. have developed linear programming model and applied it to the hypothetical agricultural holding in the hilly part of Slovenia in order to find optimal production plans by maximizing total gross margins [5].

Aryal et al. described the optimization of a complex dairy farm simulation model using two quite different methods of optimization, the genetic algorithm (GA) and the Lipschitz branch-and-bound (LBB) algorithm [6].

Scarpari and Ferreira de Beauclair developed an optimized planning model for sugarcane farming using a linear programming tool [7].

Walangitan et al. conducted a study aiming to analyze the optimal allocation of land use type in order to ensure sustainable agriculture in the catchment of the lake Tondano [8].

Hameed et al. developed an approach for coverage planning for agricultural operations involving the presence of obstacle areas within the field area [9].

Stamenkovska et al. developed an optimization model to support the analysis of decision-making on Macedonian family farms [10].

Manos et al. presented a model for sustainable optimization of agricultural production [11].

Levina proposed the ways of the optimization of the structure of production and distribution of agricultural goods by suburban enterprises of Odessa [12].

Lu et al. developed a model improved upon the existing probabilistic programming and inexact optimization approaches [13].

Osaki and Batalha brought important contributions to understand the double-crop production systems that made Brazil one of the world’s leading and most competitive grain-producing countries [14].

Bekri et al. presented a methodology that combined an ordinary multi-stage stochastic programming with uncertainties expressed as fuzzy-boundary intervals. In this work, the uncertainty of the random water inflows is incorporated through the simultaneous generation of stochastic equal-probability hydrologic scenarios at various inflow positions instead of using a scenario-tree approach in the original methodology [15].

Khoshnevisan et al. studied the life cycle assessment (LCA), multi-objective genetic algorithm (MOGA), and data envelopment analysis (DEA) was combined, and the pros and cons of their application were investigated [16].

Daghighi et al. developed a water resources planning model that helped decision-makers determine an appropriate cultivation pattern, optimize the exploitation from surface water resources, and specify the method of allocating water across different farm crops to minimize the detrimental effects of water shortage [17].

López Chavarría et al. showed two optimization models applied to crops in the agricultural production, which are 1) to maximize the utility; 2) to minimize the cost [18].

This paper presents an optimal model to maximize the utility of an agricultural company that operates several farms (general case), and the considered constraint functions are 1) land availability for each of the farms; 2) water availability for each of the farms; 3) land availability for each of the farms by each crop; 4) equal percentage of land available (proportional) for each crop. Numerical examples for an agricultural company that operates four farms are shown through two cases that are: Case 1 takes into account the three first constraints and the Case 2 considers the four constraints. These examples are presented to observe the differences between the two cases.

The paper is organized as follows. Section 2 describes the methodology for the optimal model for an agricultural company that operates several farms. Section 3 shows the numerical examples for the optimal model for an agricultural company that operates several farms. Results and discussion are presented in Section 4. Conclusion (Section 5) completes the paper.

2. **Methodology.** An agricultural company that operates several farms is modeled with constraints for solving optimization based on genetic algorithm.

The goal is that it allows the company to determine the amount (hectares) of each crop, which must be planted in each farm, so that the total expected profits are maximized.

We assume that the agricultural company operates several farms. The company grows several types of products, although each of the farms does not necessarily cultivate all the products. The total utility "U_t" of the agricultural company is obtained:

$$U_t = \sum_{i=1}^{n} \sum_{j=1}^{m} \alpha_i X_{ij} \tag{1}$$

where α is the utility per hectare for each of the crops, X is the number of hectares for each crop, $i = 1, 2, 3, \ldots, n$ (crop), $j = 1, 2, 3, \ldots, m$ (farm).

Constraint on land availability for each of the farms is as follows:

$$\sum_{i=1}^{n} X_{ij} \leq A_j \tag{2}$$

where A_j is the available total land surface for each of the farms in hectares.

Constraint on water availability for each of the farms is as follows:

$$\sum_{i=1}^{n} \beta_i X_{ij} \leq B_j \tag{3}$$

where B_j is the available total water for each of the farms in cubic meters, and β is the water required (expressed in cubic meters per hectare) for each crop.

Constraint on land availability for each of the farms by each crop is as follows:

$$X_{ij} \leq C_{ij} \tag{4}$$

where C is the number of available hectares of each farm for each crop.

Constraint on the equal percentage of the land available (proportional) for each crop is as follows:

$$\left.\begin{array}{c}\frac{\sum_{i=1}^{n} X_{i1}}{A_1}=\frac{\sum_{i=1}^{n} X_{i2}}{A_2}\\ \frac{\sum_{i=1}^{n} X_{i1}}{A_1}=\frac{\sum_{i=1}^{n} X_{i3}}{A_3}\\ \frac{\sum_{i=1}^{n} X_{i1}}{A_1}=\frac{\sum_{i=1}^{n} X_{i4}}{A_4}\\ \vdots\\ \frac{\sum_{i=1}^{n} X_{i1}}{A_1}=\frac{\sum_{i=1}^{n} X_{im}}{A_m}\end{array}\right\} \tag{5}$$

Equation (5) is for farm 1, but these must be done for each of the other farms.

3. **Numerical Examples.** An agricultural company operates four farms. The production of each farm is limited by the amount of water available for irrigation and by the number of hectares available for each crop. Table 1 describes the data of the farms. Normally, the company cultivates three types of products, although each one of the farms does not necessarily cultivate all the products. Due to the limited availability of equipment for harvest, there are restrictions on the number of hectares of each product that are grown on each farm. Table 2 reflects the data of the maximum hectares of each crop that can be produced in each farm. The water required (expressed in cubic meters per hectare) for the respective crops are: 600, 500 and 400. The projected utilities per hectare for each of the three crops are \$500.00, \$350.00 and \$200.00 (dollars), respectively.

Table 1. Availability of water and land for each farm

Farm	Water availability (m^3)	Land availability (hectares)
1	480000	450
2	320000	650
3	370000	350
4	890000	500

Table 2. Availability of maximum hectares of each crop for each farm

Crop	Farm			
	1	2	3	4
A	200	300	100	250
B	150	200	150	100
C	200	350	200	300

Objective function to maximize the utility "U_t" by Equation (1) is obtained:

$$U_t = 500(X_{11} + X_{12} + X_{13} + X_{14}) + 350(X_{21} + X_{22} + X_{23} + X_{24}) + 200(X_{31} + X_{32} + X_{33} + X_{34})$$

Constraint on land availability for each of the farms by Equation (2) is found:
Farm 1: $X_{11} + X_{21} + X_{31} \leq 450$
Farm 2: $X_{12} + X_{22} + X_{32} \leq 650$
Farm 3: $X_{13} + X_{23} + X_{33} \leq 350$
Farm 4: $X_{14} + X_{24} + X_{34} \leq 500$
Constraint on water availability for each of the farms by Equation (3) is obtained:
Farm 1: $600X_{11} + 500X_{21} + 400X_{31} \leq 480000$
Farm 2: $600X_{12} + 500X_{22} + 400X_{32} \leq 320000$

Farm 3: $600X_{13} + 500X_{23} + 400X_{33} \leq 370000$
Farm 4: $600X_{14} + 500X_{24} + 400X_{34} \leq 890000$

Constraint on land availability for each of the farms by each crop by Equation (4) is found:

Crop A: $X_{11} \leq 200$; $X_{12} \leq 300$; $X_{13} \leq 100$; $X_{14} \leq 250$
Crop B: $X_{21} \leq 150$; $X_{22} \leq 200$; $X_{23} \leq 150$; $X_{24} \leq 100$
Crop C: $X_{31} \leq 200$; $X_{32} \leq 350$; $X_{33} \leq 200$; $X_{34} \leq 300$

Constraint on the equal percentage of land available (proportional) for each crop by Equation (5) is obtained:

Farm 1 and Farm 2:
$$\frac{X_{11} + X_{21} + X_{31}}{450} = \frac{X_{12} + X_{22} + X_{32}}{650}$$
Farm 1 and Farm 3:
$$\frac{X_{11} + X_{21} + X_{31}}{450} = \frac{X_{13} + X_{23} + X_{33}}{350}$$
Farm 1 and Farm 4:
$$\frac{X_{11} + X_{21} + X_{31}}{450} = \frac{X_{14} + X_{24} + X_{34}}{500}$$
Farm 2 and Farm 3:
$$\frac{X_{12} + X_{22} + X_{32}}{650} = \frac{X_{13} + X_{23} + X_{33}}{350}$$
Farm 2 and Farm 4:
$$\frac{X_{12} + X_{22} + X_{32}}{650} = \frac{X_{14} + X_{24} + X_{34}}{500}$$
Farm 3 and Farm 4:
$$\frac{X_{13} + X_{23} + X_{33}}{350} = \frac{X_{14} + X_{24} + X_{34}}{500}$$

We study two cases:

Case 1: Constraint on the equal percentage of land available (proportional) for each crop is not considered;

Case 2: Constraint on the equal percentage of land available (proportional) for each crop is considered.

Table 3 shows the results obtained by the MAPLE-15 software.

4. **Results and Discussion.** Table 3 shows the results for the two cases taking into account the constraints following: 1) land availability for each of the farms; 2) water availability for each of the farms; 3) water availability for each of the farms by each crop; 4) equal percentage of land available (proportional) for each crop. Case 1 considers the three first constraints. Case 2 takes into account the four constraints.

The results presented in Table 3 show the following.

Case 1 has a utility maximum of 725000 dollars. The area cultivated for farm 1 must be of 200 hectares for the crop A, of 150 hectares for the crop B and of 100 hectares for the crop C. The area cultivated for farm 2 must be of 300 hectares for the crop A, of 200 hectares for the crop B and of 100 hectares for the crop C. The area cultivated for farm 3

Table 3. Solution for the two cases

Case	Variables												
	U_t	X_{11}	X_{12}	X_{13}	X_{14}	X_{21}	X_{22}	X_{23}	X_{24}	X_{31}	X_{32}	X_{33}	X_{34}
1	725000	200	300	100	250	150	200	150	100	100	100	100	150
2	705000	200	238	100	250	150	124	150	100	100	288	100	150

must be of 100 hectares for the crop A, of 150 hectares for the crop B and of 100 hectares for the crop C. The area cultivated for farm 4 must be of 250 hectares for the crop A, of 100 hectares for the crop B and of 150 hectares for the crop C.

Case 2 has a utility maximum of 705000 dollars. The area cultivated for farm 1 must be of 200 hectares for the crop A, of 150 hectares for the crop B and of 100 hectares for the crop C. The area cultivated for farm 2 must be of 238 hectares for the crop A, of 124 hectares for the crop B and of 288 hectares for the crop C. The area cultivated for farm 3 must be of 100 hectares for the crop A, of 150 hectares for the crop B and of 100 hectares for the crop C. The area cultivated for farm 4 must be of 250 hectares for the crop A, of 100 hectares for the crop B and of 150 hectares for the crop C.

The differences between the two cases are shown as follows.

1) The highest profit is for case 1 of 725000 dollars and for case 2 of 705000 dollars.

2) The area cultivated on farm 2, where the area cultivated for product A is 300 hectares for case 1 and 238 hectares for case 2, the area cultivated for product B is 200 hectares for case 1 and 124 hectares for case 2, and the area cultivated for product C is 100 hectares for case 1 and 288 hectares for case 2.

3) The area cultivated on farms 1, 3 and 4 for products A, B and C is equal for the two cases.

The importance of applying this methodology is that the fourth constraint must not necessarily be used to obtain maximum utility.

5. Conclusions.

This paper presents an optimal model for an agricultural company that operates several farms. The objective function is developed to maximize the utility of the agricultural company with the constraints following: 1) land availability for each of the farms; 2) water availability for each of the farms; 3) land availability for each of the farms by each crop; 4) equal percentage of land available (proportional) for each crop.

Numerical examples to obtain the maximum utility for an agricultural company that operates several farms have been presented to demonstrate the efficiency of the optimization techniques.

The main conclusions are shown as follows.

1) The maximum utility is presented for an agricultural company that operates several farms if there are fewer restrictions, i.e., the constraint of the equal percentage of land available (proportional) for each crop is not considered. Therefore, if we have fewer constraints, a greater utility is obtained.

2) The methodology shown in this paper is more accurate and converges more quickly. Accuracy is obtained by the equations shown in this paper and converges faster by using the software.

The proposed models can be further used to evaluate different companies of the industrial and/or commercial type and different constraints.

The suggestions for future research may consider the following constraints: the cost on preparation per unit of land (per hectare) for each crop; the cost and quantity on seeds per unit of land (per hectare) for each crop; the cost and quantity on fertilizers per unit of land (per hectare) for each crop; the cost and quantity on human power per unit of land (per hectare) for each crop; the cost and quantity on irrigation water per unit of land (per hectare) for each crop; the cost on integral control of pests and diseases per unit of land (per hectare) for each crop; the cost on harvest per unit of land (per hectare) for each crop.

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REFERENCES

[1] J. M. Sumpsi, F. Amador and C. Romero, On farmers' objectives: A multi-criteria approach, *European Journal of Operational Research*, vol.96, pp.64-71, 1997.

[2] F. Amador, J. M. Sumpsi and C. Romero, A non-interactive methodology to assess farmers' utility functions: An application to large farms in Andalusia, Spain, *European Review of Agricultural Economics*, vol.25, pp.92-109, 1998.

[3] B. J. Kurytskyy, *Search of the Optimal Solutions Funds EXCEL 7.0*, Saint Petersburg, BHV, 1977.

[4] A. Biswas and B. B. Pal, Application of fuzzy goal programming technique to land use planning in agriculture system, *Omega*, vol.33, pp.391-398, 2005.

[5] J. Žgajnar, E. Erjavec and S. Kavčič, Optimization of production activities on individual agricultural holdings in the frame of different direct payments options, *Acta Agriculturae Slovenica*, vol.90, pp.45-56, 2007.

[6] J. Aryal, G. D. Kulasiri and D. S. Liu, Optimization approaches for a complex dairy farm simulation model, *International Scholarly and Scientific Research & Innovation*, vol.2, no.2, pp.405-411, 2008.

[7] M. S. Scarpari and E. G. Ferreira de Beauclair, Optimized agricultural planning of sugarcane using linear programming, *Revista Investigación Operacional*, vol.31, no.2, pp.126-132, 2010.

[8] H. D. Walangitan, B. Setiawan, B. T. Raharjo and B. Polii, Optimization of land use and allocation to ensure sustainable agriculture in the catchment area of Lake Tondano, Minahasa, North Sulawesi, Indonesia, *International Journal of Civil & Environmental Engineering*, vol.12, no.3, pp.68-75, 2012.

[9] I. A. Hameed, D. Bochtis and C. A. Sørensen, An optimized field coverage planning approach for navigation of agricultural robots in fields involving obstacle areas, *International Journal of Advanced Robotic Systems*, vol.10, no.231, pp.1-9, 2013.

[10] I. J. Stamenkovska, D. Dimitrievski, E. Erjavec, J. Žgajnar and A. Martinovska-Stojcheska, Optimization of production on vegetable farm in the Republic of Macedonia, *Agroeconomia Croatica*, vol.3, no.1, pp.1-8, 2013.

[11] B. Manos, P. Chatzinikolaou and F. Kiomourtzi, Sustainable optimization of agricultural production, *APCBEE Procedia*, vol.5, pp.410-415, 2013.

[12] M. Levina, The optimization of the structure of production and distribution of agricultural goods by suburban enterprises of Odessa, *Problems and Perspectives in Management*, vol.11, no.3, pp.56-62, 2013.

[13] S.-S. Lu, Y. Liu, H. Long and X.-H. Guan, Agricultural production structure optimization: A case study of major grain producing areas, China, *Journal of Integrative Agriculture*, vol.12, no.1, pp.184-197, 2013.

[14] M. Osaki and M. O. Batalha, Optimization model of agricultural production system in grain farms under risk, in Sorriso, Brazil, *Agricultural Systems*, vol.12, pp.178-188, 2014.

[15] E. Bekri, M. Disse and P. Yannopoulos, Optimizing water allocation under uncertain system conditions for water and agriculture future scenarios in Alfeios River Basin (Greece) – Part B: Fuzzy-boundary intervals combined with multi-stage stochastic programming model, *Water*, vol.7, pp.6427-6466, 2015.

[16] B. Khoshnevisan, E. Bolandnazar, S. Shamshirband, H. M. Shariati, N. B. Anuar and M. L. Kiah, Decreasing environmental impacts of cropping systems using life cycle assessment (LCA) and multiobjective genetic algorithm, *Journal of Cleaner Production*, vol.86, no.1, pp.67-77, 2015.

[17] A. Daghighi, A. Nahvi and U. Kim, Optimal cultivation pattern to increase revenue and reduce water use: Application of linear programming to Arjan Plain in Fars Province, *Agriculture*, vol.7, no.9, 2017.

[18] S. López Chavarría, A. Luévanos Rojas, M. Medina Elizondo and M. del Carmen Armenteros Acosta, Optimization models applied to crops in the agricultural production of México, *ICIC Express Letters, Part B: Applications*, vol.8, no.3, pp.477-482, 2017.