Mitigation of the effects of climate change in the agricultural sector of Cyprus, through optimization of benefit

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ABSTRACT

Water scarcity has a significant impact on agricultural productivity, and it usually constitutes the main criterion for the continuation of agricultural activity. The Cyprus agri-sector faces increasing challenges since water resources are very limited and particularly susceptible to climate change. As total profit highly depends on cultivation patterns, the present study aims to define the optimal pattern of agricultural crops in Cyprus. A linear programming model is set up to maximize the net profit of annual and permanent crops. As for the constraints, these include limitations on land and water availability under four different scenarios, provided that production secures current consumption of (1) domestic products, (2) domestic and imported products, (3) domestic products but under a 40% decrease in water availability and (4) domestic products but limited to only traditional, tropical and subtropical crops, under a 40% decrease in water availability. The results indicate that when using an optimal cultivation pattern, economic benefit increases by 120%, 62%, 20%, and 48%, based on Scenarios 1, 2, 3 and 4, respectively. Furthermore, the results are considered useful and directly applicable for policy makers to redesign their strategy in light of water scarcity.

Key words | agriculture, climate change, Cyprus, irrigation, linear programming

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HIGHLIGHTS

- Water scarcity in Cyprus impacts the agri-sector, leading to high economic losses.
- Linear programming can provide optimal cultivation patterns to maximize economic benefit.
- If Cypriot agriculture shifts to less water-intensive/higher-added-value crops, an increase in economic benefit is achieved, even with significant water reduction.
- Linear Programming results provide a valuable tool for policy makers, in light of climate change.

INTRODUCTION

The agricultural sector is considered one of the most dynamic and important sectors for economic development on the entire planet, playing a vital role in food security. A dedicated Sustainable Development Goal (SDG2), based on specific key performance indicators to be reached by 2030, provides a comprehensive approach to tackling food insecurity while promoting sustainable agriculture. In most countries, the agri-sector represents a huge fraction of total manufacturing benefit and is significantly important for gross domestic product (GDP). At the same time, however,

doi: 10.2166/ws.2021.118

the agri-sector is responsible for major environmental problems, such as greenhouse gas (GHG) emissions and excessive water demands. In contrast, in various eastern Mediterranean countries and in Cyprus, Greece (Crete region), Sicily, Spain, Morocco, and Tunisia, water scarcity is considered to be a critical problem, with adverse effects on the agri-sector (Bonneau *et al.* 2017; Luque *et al.* 2017; Tsangas *et al.* 2020).

In general, the agri-sector is the one sector of the economy that will likely be hit the hardest by climate change since it directly depends on environmental and climatic factors, such as precipitation, temperature, sunlight, water consumption and deforestation (Doula *et al.* 2019; Cradock-Henry *et al.* 2020; Ioannou *et al.* 2020; Tsangas *et al.* 2020). The magnitude of these effects is strongly related to the existing agricultural approaches and practices applied (Navarro-Pedreño *et al.* 2018; Recanati *et al.* 2018; Soudejani *et al.* 2019).

According to the European Environment Agency (EEA 2008), climate change affects crop yields, the growing season and the timing of the crop life cycle. While climate change is projected to have some positive effects through improved crop-growing conditions in northern Europe (Peltonen-Sainio *et al.* 2009), southern Europe is expected to experience adverse effects, including declining crop yields, decreasing soil (Almendro-Candel *et al.* 2018), organic matter (Escolano *et al.* 2018), water resources, as well as desertification (Behrens *et al.* 2010). Especially, the Mediterranean region is expected to face the most adverse effects on natural conditions for crop cultivation, leading to higher economic losses (Jones *et al.* 2003; Porter & Semenov 2005; Norrant & Douguédroit 2006; EEA 2008; Iglesias *et al.* 2010). Furthermore, taking into account the report released by the Intergovernmental Panel on Climate Change (IPCC 2007), the entire Mediterranean ecosystem is susceptible to climate variation since the availability of water is limited, as well as due to the increase of desertification risk (Meléndez-Pastor *et al.* 2017). The quantity and rate of water, oxygen, and nutrient absorption by plants depend on the ability of the roots to absorb the soil solution and the ability of the soil to supply it to the roots. Low hydraulic conductivity, as one of the main soil properties affected by climate conditions, may reduce the availability of free water supply and oxygen to the roots, which has a direct negative affect on agricultural yield (Escolano *et al.* 2018).

In particular, the agricultural sector of Cyprus, which has always been an economic sector of great importance for the island, faces increasing challenges due to climate change (Marcou *et al.* 2011). The island has a semi-arid climate and limited water resources that depend mainly on rainfall. However, rainfall is unevenly distributed, with temporal and geographical variations. Forecasts from regional climate model simulations for the twenty-first century highlight the vulnerability of Cyprus to climate change by projecting an increase in temperature and a decrease in rainfall by the end of the century (Zachariadis 2016). According to universal projections, these conditions affect the physical properties of soil, which are vital for the agri-sector (Escolano *et al.* 2018).

Water is a fundamental resource for agricultural productivity with water footprint being a very crucial indicator for the agri-sector, in general (Goudouva & Zorpas 2017). The water scarcity problem in Cyprus has already had a negative impact on the island's agri-sector and in many cases, the degree of irrigation is the main condition for the continuation of an agricultural activity. The aim of the agricultural sector under the pressure of climate change should be water saving, as well as the allocation of this limited and valuable resource to crops, which could potentially be in a position to bring the maximum economic benefit (Gruda *et al.* 2019). The allocation of crops is also linked to land use planning and management, which in turn has an impact on many socio-economic sectors (Escolano *et al.* 2018). Unless suitable land management procedures are implemented, more frequent and more severe droughts will cause soil water retention mechanisms to collapse, resulting in the onset of erosion and desertification (JRC 2012).

Within this context, the purpose of the present paper is to define the optimum cultivation pattern of the main agricultural crops in Cyprus, for maximizing the net economic profit, under limited water use constraints.

MATERIALS AND METHODS

A literature review shows that optimization methods are very effective tools for water resources management, and in particular for finding optimum agricultural cultivation patterns (Sarker & Ray 2009; Mansourifar et al. 2013). Numerous other empirical studies have revealed that linear programming (LP) is one of the best approaches for optimization, because of its simplicity and applicability (Singh et al. 2001; Zare & Koch 2014).

In the present paper, a linear programming model was formulated with the objective of finding an optimal cropping pattern that results in a maximum net profit, consisting of the following components: the decision variables, which quantify the decisions that need to be taken, the objective function, which quantifies the measure of performance to be maximized or minimized, and a set of constraints, which reflect the physical limitations of some or all decision variables. The LP model was formulated and solved using the MS Excel Solver add-in (Simplex method).

Decision variables

In accordance with the Statistical Service of Cyprus, the decision variables were defined as the cultivated areas of the main crops produced on the island (Statistical Service of Cyprus 2019). The crops were divided into two categories, which do not compete with each other, the annual (i) and the permanent (j) crops. An additional scenario was also formulated considering only the traditional, tropical, and subtropical crops (k) that grow on the island.

The annual crops (i) include eight different types of crops: Wheat, Barley, Tomatoes, Cucumbers, Watermelons, Sweet Melons, Carrots and Potatoes, with a total existing cultivated area of 24,900 hectares. The permanent crops (j) include 18 types: Olives, Carobs, Almonds, Apples, Pears, Cherries, Peaches, Avocado, Oranges, Grapefruit, Lemons, Bananas, Kiwi, Plums, Figs, Artichokes, Wine Grapes and Table Grapes, with a total existing cultivated area of 23,685 hectares. The traditional, tropical and subtropical crops (k) include nine types: Olives, Carobs, Wheat, Avocado, Bananas, Kiwi, Plums, Figs and Artichokes, with a total existing cultivated area of 21,419 hectares.

Objective function

The objective function for each crop category aims to maximize the total annual net profit, denoted by Z, for the selected crops, according to the mathematical equations presented below.

For the annual crops, i (1–8):

$$\text{Max}\, Z_i = \sum_{i=1}^{8} A_i(R_i - E_i)$$

For the permanent crops, j (1–18):

$$\text{Max}\, Z_j = \sum_{j=1}^{18} A_j(R_j - E_j)$$

For the traditional, tropical and subtropical crops, k (1–9):

$$\text{Max}\, Z_k = \sum_{k=1}^{9} A_k(R_k - E_k)$$

The term R (R_i or R_j or R_k) denotes the total Revenues for each type of crop per hectare, based on the expected sale price. The term E (E_i or E_j or E_k) denotes the total Expenses for each type of crop and includes all variable costs per hectare, such as fertilizers, irrigation, mechanical work, electricity, external labor and more. The term A (A_i or A_j or A_k) denotes the optimal cultivated area by each type of crop that results in a net profit maximization. These are the decision variables, which will constitute our proposals.

Constraints

In the present study, land and water constraints have been used. For the land constraints, both maximum and minimum limits have been set. The maximum limit was used based on the assumption that the total area of the existing cultivated land will not change. The minimum limit on the cultivated land has been introduced to ensure that domestic production covers the current consumption needs of the products.

Regarding irrigation water, the basic assumption of the model is that total irrigation water consumed should not exceed the total quantity currently consumed by the existing crops. Furthermore, it was assumed that the efficiency of the irrigation networks in Cyprus is 85%.

Scenarios

Four scenarios were applied to the model, to determine various proposals for the agricultural sector of Cyprus. In the first scenario, it was assumed that (a) the total area of cultivated land per crop category (annual and permanent) does not exceed the total cultivated land of the existing crops, per category, (b) the minimum areas of crops should ensure that domestic production covers the current consumption needs in domestic products, with the remaining needs of the population to be covered by imports, and (c) total irrigation water does not exceed current consumption in irrigation water.

The constraints in the second scenario are the same as the ones in the first scenario in terms of maximum land areas and maximum water consumption. What differs is the assumption that the minimum areas of crops should ensure the total consumption of all products. More specifically, all products (both domestic and imported) that are currently consumed should be produced in Cyprus.

The constraints in the third scenario are the same as the ones in the first scenario in terms of maximum and minimum areas. The difference is in the assumption that irrigation water is reduced by 40%.

The main assumption of the fourth scenario is that under the pressure of climate change, only traditional, tropical and subtropical crops can grow and thrive in Cyprus. Also, similarly to the first and third scenarios, the minimum areas of crops should ensure that domestic production covers the current consumption needs in domestic products, with the remaining needs of the population to be covered by imports. Furthermore, water availability is reduced by 40%, due to climate change. It is noted that under this scenario, the proposed crops could potentially cover the total existing area cultivated by all other current crops. However, for direct comparison, the maximum area used is the one taken up by the traditional, tropical and subtropical crops that are currently cultivated.

RESULTS AND DISCUSSION

Scenario 1 – annual crops

The results of the LP model for the annual crops under Scenario 1, for which (a) the minimum cultivated areas should cover the current consumption needs in domestic products, supplementing the remaining needs with imports, and (b) the total irrigation water does not exceed current consumption in irrigation water, are presented in Table 1.

Table 1 | Scenario 1 – results of the linear programming model for the annual crops

		Irrigation needs per hectare	Revenue – Expenses per hectare	Cultivated Area		Net Profit		
				A_i		$Z = A_i(R_i - E_i)$		
i	**Crop**	IRR_i (m^3/ha)	$R_i - E_i$ (€/ha)	**Existing Area (ha)**	**Proposed Area (ha)**	**With Existing Area (€ mil.)**	**With Proposed Area (€ mil.)**	**Incr./(Decr.) (%)**
1	Wheat	–	430	8,678	**21,766**	3.7	**9.4**	*151%*
2	Barley	–	287	10,953	**–**	3.1	**–**	*(100%)*
3	Tomatoes	6,394	45,832	261	**2,192**	12.0	**100.5**	*740%*
4	Cucumbers	4,761	4,211	190	**188**	0.8	**0.8**	*(1%)*
5	Watermelons	4,988	16,406	436	**435**	7.2	**7.1**	*(0.1%)*
6	Sweet Melons	5,192	17,564	146	**146**	2.6	**2.6**	*(0.1%)*
7	Carrots	4,244	12,506	57	**54**	0.7	**0.7**	*(6%)*
8	Potatoes	3,035	8,261	4,179	**119**	34.5	**1.0**	*(97%)*
Total				**24,900**	**24,900**	**65**	**122**	***89%***

Note: values in bold type specify (1) all Total values and (2) Proposed Cultivated Areas and Net Profit that corresponds to Proposed Cultivated Areas.

According to the model, the total net profit of annual crops may increase by 89% if the cultivations of tomatoes and wheat are increased by 740% and 150%, respectively. On the other hand, barley should be entirely omitted from the cultivation pattern, and the rest of the crops should be produced in the minimum possible quantity to cover domestic consumption. These results were expected since the net profit for the tomato crops, which is €45,832/ha, is multiple times higher than the net profit of the rest.

In the case of wheat, the low net profit of the crop is offset by the fact that it requires no irrigation water, however in the case of barley, even though it also has no irrigation requirements, its low net profit makes it unprofitable as a crop. It is worth noting that for the cultivation of potato, which today is the main exported agricultural product for Cyprus, even though its irrigation water requirements are not prohibitively high (3,035 m^3/ha), its low net profit (€8,261/ha) compared with the rest of the irrigated crops results in a reduction of the crop.

Scenario 1 – permanent crops

The proposed quantities of the permanent crops under Scenario 1 are shown in Table 2.

The crops that should be increased are figs (by 4,500%) and to a lesser extent wine grapes (by 83%). The rest of the crops should be produced in the minimum possible quantity just to cover domestic consumption, whereas the cultivation of carob trees is omitted completely.

The explanation of the results under this scenario is similar to the explanation provided in the case of the annual crops. Figs have the highest net profit (€46,000/ha) and relatively low water needs; as a result, they are ranked as the top crop with the highest productivity. In the case

Table 2 | Scenario 1 – results of the linear programming model for the permanent crops

		Irrigation needs per hectare	**Revenue – Expenses per hectare**	**Cultivated Area**		**Net Profit**		
				A_j		$Z = A_j(R_j - E_j)$		
j	**Crop**	IRR_j **(m³/ha)**	$R_j - E_j$ **(€/ha)**	**Existing Area (ha)**	**Proposed Area (ha)**	**With Existing Area (€ mil.)**	**With Proposed Area (€ mil.)**	**Incr./(Decr.) (%)**
1	Olives	4,307	5,285	10,830	**1,678**	57.2	**8.9**	*(85%)*
2	Carobs	–	927	982	**–**	0.9	**–**	*(100%)*
3	Almonds	3,540	3,874	2,195	**1,978**	8.5	**7.7**	*(10%)*
4	Apples	6,821	19,886	372	**371**	7.4	**7.4**	*(0%)*
5	Pears	6,821	25,414	66	**66**	1.7	**1.7**	*(0%)*
6	Cherries	6,821	27,390	227	**225**	6.2	**6.2**	*(1%)*
7	Peaches	6,821	14,146	297	**297**	4.2	**4.2**	*(0%)*
8	Avocado	8,468	15,363	77	**77**	1.2	**1.2**	*0%*
9	Oranges	8,468	2,239	1,090	**603**	2.4	**1.3**	*(45%)*
10	Grapefruit	8,468	474	413	**113**	0.2	**0.1**	*(73%)*
11	Lemons	8,468	3,023	363	**153**	1.1	**0.5**	*(58%)*
12	Bananas	12,559	7,047	211	**207**	1.5	**1.5**	*(2%)*
13	Kiwi	6,821	1,593	2	**2**	0.0	**0.0**	*0%*
14	Plums	6,821	9,233	383	**383**	3.5	**3.5**	*(0%)*
15	Figs	6,821	28,061	163	**7,471**	4.6	**209.6**	*4,483%*
16	Artichokes	4,405	14,190	93	**93**	1.3	**1.3**	*(0%)*
17	Wine Grapes	–	2,302	5,313	**9,732**	12.2	**22.4**	*83%*
18	Table Grapes	3,082	6,149	608	**237**	3.7	**1.5**	*(61%)*
Total				**23,685**	**23,685**	**118**	**279**	***136%***

Note: values in bold type specify (1) all Total values and (2) Proposed Cultivated Areas and Net Profit that corresponds to Proposed Cultivated Areas.

of grapes, the model has picked wine grapes, when compared with table grapes, even if they have a lower net profit, due to the fact that they do not require any water, which makes them more productive relative to water.

It is interesting to note the results of olive and carob trees, which are considered traditional crops and part of the Cypriot rural environment. In the case of carob, which is a non-irrigated crop, the very low net profit for the raw product (€927/ha) is the reason for its removal from the proposed cultivation pattern. In the case of olive, even though its net profit is relatively high (€5,285/ha) and its water requirements are relatively low (4,307 m^3/ha), it is not ranked by the model as the crop with the highest economic productivity. Under Scenario 1, citrus, another main exported product, is also negatively affected. Its high water requirements, combined with its low net profit, make it a non-profitable crop.

Scenario 2 – annual crops

Under Scenario 2, for which (a) the minimum areas of crops should ensure the total consumption of all products, including imported, and (b) the total irrigation water should not exceed current consumption, the total net profit of annual crops increases by 87% (see Table 3). Also, in this case, the tomato and wheat crops have the greatest increase, 722% and 150%, respectively. Furthermore, the potato crops are reduced under this scenario, for the reasons mentioned earlier.

Scenario 2 – permanent crops

The results of the permanent crops under Scenario 2 are indicated in Table 4.

In this case, there is also an increase in the total net profit (48%), but to a lesser extent, compared with Scenario 1. Again, figs and wine grapes are increased by 1,090% and 21%, respectively, whereas the rest of the crops are increased in the minimum possible quantity to cover consumption needs. In Scenario 2, carobs are also omitted completely and citrus trees are reduced to the minimum necessary quantities.

Scenario 3 – annual crops

The results of the LP model for the annual crops under Scenario 3, for which (a) the minimum areas of crops should cover current consumption needs in domestic products, and (b) total irrigation water is reduced by 40%, are indicated in Table 5.

The results show that even if the available quantities of water are decreased by 40%, which is a possible future

Table 3 | Scenario 2 – results of the linear programming model for the annual crops

		Irrigation needs per hectare	Revenue – Expenses per hectare	Cultivated Area		Net Profit		
				A_i		$Z = A_i(R_i - E_i)$		
i	Crop	IRR_i (m^3/ha)	$R_i - E_i$ (€/ha)	Existing Area (ha)	Proposed Area (ha)	With Existing Area (€ mil.)	With Proposed Area (€ mil.)	Incr./(Decr.) (%)
1	Wheat	–	430	8,678	**21,732**	3.7	**9.3**	*150%*
2	Barley	–	287	10,953	**–**	3.1	**–**	*(100%)*
3	Tomatoes	6,394	45,832	261	**2,145**	12.0	**98.3**	*722%*
4	Cucumbers	4,761	4,211	190	**191**	0.8	**0.8**	*0%*
5	Watermelons	4,988	16,406	436	**442**	7.2	**7.2**	*1%*
6	Sweet Melons	5,192	17,564	146	**148**	2.6	**2.6**	*1%*
7	Carrots	4,244	12,506	57	**83**	0.7	**1.0**	*45%*
8	Potatoes	3,035	8,261	4,179	**160**	34.5	**1.3**	*(96%)*
Total				**24,900**	**24,900**	**65**	**121**	***87%***

Note: values in bold type specify (1) all Total values and (2) Proposed Cultivated Areas and Net Profit that corresponds to Proposed Cultivated Areas.

Table 4 | Scenario 2 – results of the linear programming model for the permanent crops

		Irrigation needs per hectare	Revenue – Expenses per hectare	Cultivated Area A_j		Net Profit $Z = A_j(R_j - E_j)$		
j	Crop	IRR_j (m^3/ha)	$R_j - E_j$ (€/ha)	Existing Area (ha)	Proposed Area (ha)	With Existing Area (€ mil.)	With Proposed Area (€ mil.)	Incr./(Decr.) (%)
1	Olives	4,307	5,285	10,830	**1,680**	57.2	**8.9**	*(84%)*
2	Carobs	–	927	982	**–**	0.9	**–**	*(100%)*
3	Almonds	3,540	3,874	2,195	**8,920**	8.5	**34.6**	*306%*
4	Apples	6,821	19,886	372	**944**	7.4	**18.8**	*154%*
5	Pears	6,821	25,414	66	**317**	1.7	**8.1**	*381%*
6	Cherries	6,821	27,390	227	**546**	6.2	**14.9**	*140%*
7	Peaches	6,821	14,146	297	**318**	4.2	**4.5**	*7%*
8	Avocado	8,468	15,363	77	**131**	1.2	**2.0**	*70%*
9	Oranges	8,468	2,239	1,090	**620**	2.4	**1.4**	*(43%)*
10	Grapefruit	8,468	474	413	**115**	0.2	**0.1**	*(72%)*
11	Lemons	8,468	3,023	363	**228**	1.1	**0.7**	*(37%)*
12	Bananas	12,559	7,047	211	**396**	1.5	**2.8**	*88%*
13	Kiwi	6,821	1,593	2	**16**	0.0	**0.0**	*712%*
14	Plums	6,821	9,233	383	**483**	3.5	**4.5**	*26%*
15	Figs	6,821	28,061	163	**1,939**	4.6	**54.4**	*1,090%*
16	Artichokes	4,405	14,190	93	**94**	1.3	**1.3**	*1%*
17	Wine Grapes	–	2,302	5,313	**6,446**	12.2	**14.8**	*21%*
18	Table Grapes	3,082	6,149	608	**492**	3.7	**3.0**	*(19%)*
Total				**23,685**	**23,685**	**118**	**175**	***48%***

Note: values in bold type specify (1) all Total values and (2) Proposed Cultivated Areas and Net Profit that corresponds to Proposed Cultivated Areas.

Table 5 | Scenario 3 – results of the linear programming model for the annual crops

		Irrigation needs per hectare	Revenue – Expenses per hectare	Cultivated Area A_i		Net Profit $Z = A_i(R_i - E_i)$		
i	Crop	IRR_i (m^3/ha)	$R_i - E_i$ (€/ha)	Existing Area (ha)	Proposed Area (ha)	With Existing Area (€ mil.)	With Proposed Area (€ mil.)	Incr./(Decr.) (%)
1	Wheat	–	430	8,678	**22,919**	3.7	**9.9**	*164%*
2	Barley	–	287	10,953	**–**	3.1	**–**	*(100%)*
3	Tomatoes	6,394	45,832	261	**1,039**	12.0	**47.6**	*298%*
4	Cucumbers	4,761	4,211	190	**188**	0.8	**0.8**	*(1%)*
5	Watermelons	4,988	16,406	436	**435**	7.2	**7.1**	*(0.1%)*
6	Sweet Melons	5,192	17,564	146	**146**	2.6	**2.6**	*(0.1%)*
7	Carrots	4,244	12,506	57	**54**	0.7	**0.7**	*(6%)*
8	Potatoes	3,035	8,261	4,179	**119**	34.5	**1.0**	*(97%)*
Total				**24,900**	**24,900**	**65**	**70**	***8%***

Note: values in bold type specify (1) all Total values and (2) Proposed Cultivated Areas and Net Profit that corresponds to Proposed Cultivated Areas.

scenario under the pressure of climate change, the total net profit could potentially be increased by 8%. The pattern includes the same prevailing crops as in the previous scenarios, tomatoes and wheat, which are increased by 298% and 164%, respectively.

Scenario 3 – permanent crops

Similarly, for the permanent crops under Scenario 3 (see Table 6), there is an increase in the total net profit by 26%, and figs and wine grapes also prevail.

Scenario 4 – traditional, tropical and subtropical crops

The results of the LP model for the annual crops under Scenario 4, which is an extreme case of extended water scarcity and droughts, under which only traditional, tropical and subtropical crops can grow when water availability is reduced by 40%, are presented in Table 7. In addition, the minimum cultivated areas should ensure that domestic production covers current consumption of existing domestic production, with the remaining needs of the population to be covered by imports.

The total net profit under Scenario 4 is increased by 48%. In this case, there is also an increase in figs by 1,604% and for the first time, carob trees appear in the cultivation pattern. The rest of the crops are limited to the minimum possible areas, just to cover the consumption of current production.

The overall results of the linear programming model are indicated in Table 8. In summary, there is an increase in the total net profit for all categories of crops, under all four

Table 6 | Scenario 3 – results of the linear programming model for the permanent crops

		Irrigation needs per hectare	Revenue – Expenses per hectare	Cultivated Area		Net Profit		
				A_j		$Z = A_j(R_j - E_j)$		
j	Crop	IRR_j (m^3/ha)	$R_j - E_j$ (€/ha)	Existing Area (ha)	Proposed Area (ha)	With Existing Area (€ mil.)	With Proposed Area (€ mil.)	Incr./(Decr.) (%)
1	Olives	4,307	5,285	10,830	**1,678**	57.2	**8.9**	*(85%)*
2	Carobs	–	927	982	**–**	0.9	**–**	*(100%)*
3	Almonds	3,540	3,874	2,195	**1,978**	8.5	**7.7**	*(10%)*
4	Apples	6,821	19,886	372	**371**	7.4	**7.4**	*(0%)*
5	Pears	6,821	25,414	66	**66**	1.7	**1.7**	*(0%)*
6	Cherries	6,821	27,390	227	**225**	6.2	**6.2**	*(1%)*
7	Peaches	6,821	14,146	297	**297**	4.2	**4.2**	*(0%)*
8	Avocado	8,468	15,363	77	**77**	1.2	**1.2**	*0%*
9	Oranges	8,468	2,239	1,090	**603**	2.4	**1.3**	*(45%)*
10	Grapefruit	8,468	474	413	**113**	0.2	**0.1**	*(73%)*
11	Lemons	8,468	3,023	363	**153**	1.1	**0.5**	*(58%)*
12	Bananas	12,559	7,047	211	**207**	1.5	**1.5**	*(2%)*
13	Kiwi	6,821	1,593	2	**2**	0.0	**0.0**	*0%*
14	Plums	6,821	9,233	383	**383**	3.5	**3.5**	*(0%)*
15	Figs	6,821	28,061	163	**2,422**	4.6	**68.0**	*1,386%*
16	Artichokes	4,405	14,190	93	**93**	1.3	**1.3**	*(0%)*
17	Wine Grapes	–	2,302	5,313	**14,781**	12.2	**34.0**	*178%*
18	Table Grapes	3,082	6,149	608	**237**	3.7	**1.5**	*(61%)*
Total				**23,685**	**23,685**	**118**	**149**	***26%***

Note: values in bold type specify (1) all Total values and (2) Proposed Cultivated Areas and Net Profit that corresponds to Proposed Cultivated Areas.

Table 7 | Scenario 4 – results of the linear programming model for the traditional, tropical and subtropical crops

		Irrigation needs per hectare	Revenue – Expenses per hectare	Cultivated Area		Net Profit		
				A_k		$Z = A_k(R_k - E_k)$		
k	Crop	IRR_k (m^3/ha)	$R_k - E_k$ (€/ha)	Existing Area (ha)	Proposed Area (ha)	With Existing Area (€ mil.)	With Proposed Area (€ mil.)	Incr./(Decr.) (%)
1	Olives	4,307	5,285	10,830	**1,678**	57.2	**8.9**	*(85%)*
2	Carobs	–	927	982	**16,142**	0.9	**15.0**	*1,544%*
3	Wheat	–	430	8,678	**60**	3.7	**0.0**	*(99%)*
4	Avocado	8,468	15,363	77	**77**	1.2	**1.2**	*0%*
5	Bananas	12,559	7,047	211	**207**	1.5	**1.5**	*(2%)*
6	Kiwi	6,821	1,593	2	**2**	0.003	**0.003**	*0%*
7	Plums	6,821	9,233	383	**383**	3.5	**3.5**	*(0%)*
8	Figs	6,821	28,061	163	**2,777**	4.6	**77.9**	*1,604%*
9	Artichokes	4,405	14,190	93	**93**	1.3	**1.3**	*(0.4%)*
Total				**21,419**	**21,419**	**74**	**109**	***48%***

Note: values in bold type specify (1) all Total values and (2) Proposed Cultivated Areas and Net Profit that corresponds to Proposed Cultivated Areas.

Table 8 | Summary of results of the linear programming model for all scenarios

	Annual Crops			Permanent Crops			All Crops		
Scenario	With Exist. Area (€ mil.)	With Prop. Area (€ mil.)	*Incr./ (Decr.) (%)*	With Exist. Area (€ mil.)	With Prop. Area (€ mil.)	*Incr./ (Decr.) (%)*	With Exist. Area (€ mil.)	With Prop. Area (€ mil.)	*Incr./ (Decr.) (%)*
1	65	122	*89%*	118	279	*136%*	183	401	*120%*
2	65	121	*87%*	118	175	*48%*	183	295	*62%*
3	65	70	*8%*	118	149	*26%*	183	218	*20%*
4							74	109	*48%*

scenarios. The most considerable increase is observed in Scenario 1, a smaller increase in Scenario 2, and the smallest increase in Scenario 3, as was expected due to reduced water availability. Under the fourth scenario, the combination of traditional, tropical and subtropical crops results in an increase in the total net profit by 48%, even with water availability reduced by 40%.

Limitations

Linear programming is a simple and effective tool that can easily determine the optimal solution to a problem under specific conditions and constraints. However, the reliability and accuracy of the model is as good as its assumptions.

For the simulation of the problem, not all categories of crops produced in Cyprus have been selected, due to data unavailability. As a result, crops with an even higher profitability may not have been included. In addition, in the formulation of the model constraints, no upper limits have been set for the cultivated area, which exist due to variations in the soil morphology and microclimatic conditions – not all crops can grow everywhere. Furthermore, the model does not take into account any variations in the product sale prices, which may arise if the existing market equilibrium is disturbed. If there is a change in prices, for example, if the surplus of products does not follow the export route, there is a possibility of revenue loss from lower market prices due to oversupply. Finally, it should be noted that over the years, a specific cultivation structure has been formed, based on the knowledge, skills and dedication of the rural population, something that is difficult to change.

Despite the model's limitations, it can be assumed that the relatively high increase in the net profit from the theoretical application of the various scenarios provides some cushion, in case the adopted cultivation pattern deviates to some degree from the theoretical one.

CONCLUSIONS

The results of the LP model show that the use of an optimal cultivation pattern maximizes the economic benefit, compared with the current cultivation pattern. The cultivations of tomato, wheat, figs and wine grapes prevail in the proposed cultivation patterns, as they all present high net profit compared with their irrigation water requirements, displacing other cultivations with lower profitability.

Exports should be limited to products with significantly higher profitability, based on the local conditions of Cyprus, such as cultivations of tomatoes, figs and wine grapes. The value of olives and carobs does not seem to be recognized by the model, since the revenue figures are based on the selling prices of the raw products, without taking into account the potential of the final processed products. For example, the carob tree is considered as an indigenous species of the island, fully adapted to the local conditions, and according to the new consumer trends towards superfoods, the prospect of the processed product is promising.

The prospect of the carob tree is recognized in the scenario of extended water scarcity, high temperatures and low crop productivity (Scenario 4), which is possible, according to the literature review, in a time span of ten to 30 years from now. Under these circumstances, most of the crops that are cultivated currently, such as citrus, vegetables, even grapes, may not be sustained under future climatic conditions and as a consequence, Cyprus may not be in a position to be self-sustained in food production. However, if a shift is made towards more traditional, tropical and subtropical crops, an increase in economic benefit could be achieved, even with a significant reduction in water availability. It should be noted though that this scenario does not take into account the fact that the cost of imports may increase, since all products consumed today may be imported rather than produced domestically.

Summing up, to tackle the challenges of climate change and protect agricultural production and income, Cypriot agriculture should, in the medium term, make a shift towards less water-intensive and higher added-value crops, such as figs, wine grapes, tomatoes and wheat. In the long term, the agricultural sector should make a gradual shift to species which are better suited for dry conditions and allow for profit maximization, without additional burden on water consumption. In order to achieve these goals, appropriate incentives should be provided to the farmers, for example through funding mechanisms, such as the Rural Development Program, for the cultivation and processing of such varieties, especially in the superfood category, that have a promising prospect in the future.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 29 January 2021; accepted in revised form 9 April 2021. Available online 20 April 2021