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Suitable Cropping Patterns for the Egyptian Desert Lands on the Context of Groundwater Limitation

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Abstract

Egypt is predominantly desert and only 5% of Egypt's total land is cultivated and permanently settled. It is well-known that soil and water are fundamental resources for agriculture. However, water is the most limiting factor for crops' productivity. Unfortunately, water resources in Egypt are becoming scarce. Surface-water resources originating from the Nile are now fully exploited, while groundwater resources are limited. The objectives of this study are mainly concerned with a descriptive and quantitative analysis of the available land and groundwater resources in Egypt. Besides, determining suggested cropping patterns in desert lands on the light of groundwater limitation. To fulfill the study main goals, a non–linear programming model was applied to achieve this purpose considering groundwater constraints. The objective function is concerned with maximizing the net revenue of the irrigation groundwater per unit. This study depends of secondary data collected from different sources. The results of this study show that, among the cropping patterns obtained by the five models, the third model is the best cropping pattern because it maximizes the net profit, followed by the fourth model. These two models save approximately 45.8% and 35.5% of the available groundwater resources for a hundred of years respectively. Although the first and the second models save approximately 61.4% and 54.2% of groundwater consumption respectively, these two models reduce the net revenue, estimated at approximately 26.9% and 36.0% out of the highest net revenue respectively.

Key words: economic; cropping patterns; desert; groundwater; Egypt

1. Introduction

Egypt is predominantly desert and only 5% of its total land is cultivated and permanently settled. It is well-known that soil and water are fundamental resources for agriculture. Supplying adequate quantities of water together with fertile soil enable farmers achieve successful agriculture.

However, water is the most limiting factor for crops' productivity. Unfortunately, water resources in Egypt are becoming scarce. Surface-water resources originating from the Nile are now fully exploited, while groundwater resources are limited. As a natural resource, groundwater is difficult to be managed. Despite land reclamation, the main obstacle in desert reclamation is supplying irrigation water. This fact clarifies the importance of exploiting other water resources such as groundwater.

The problem of this study is concerned with the use of surface water resources in agricultural horizontal expansion, especially in desert lands, that doesn't have high revenues because of the high costs of pumping groundwater to the surface for irrigation use furthermore, cultivating unsuitable crops in accordance with the available irrigation water and thus, reducing water productivity.

The objectives of this study are mainly concerned with a descriptive and quantitative analysis of the available land and groundwater resources in Egypt. Besides, determining suggested cropping patterns in desert lands on the light of groundwater limitation.

2. Methodological Framework

To fulfill the study main goals, a non–linear programming model was applied to achieve this purpose considering groundwater constraints. This study depends of secondary data collected from different sources.

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This study aims at suggesting the cropping patterns that can maximize the groundwater productivity. The objective function of the non–linear programming model is concerned with maximizing the net revenue of the irrigation groundwater per unit.

The constraints of this model concerned with the available groundwater, estimated at 4 billion cubic meters (B.C.M.) annually. These constraints also include land resources, where the cultivated area in desert lands doesn't exceed 533 thousand feddans annually, taking into consideration cultivating an area estimated at 220 thousand feddans for the first model, to be increased by 20% in the second model, then by another 20% in the third model and this method is also applied for the fourth and fifth models. This cultivated area includes winter, summer and permanent crops.

The non-linear programming model depends on the agricultural activities supply function as following, (LINDO, 1997 and 2001):

$X_n = a + bQ_n$ …………………....(1)

Where,

X : is the price per unit (L.E.).

a, b : are the parameters of the agricultural activities supply function.

Q : is the quantity of production per unit.

$n's$: are the agricultural activities of the suggested model (1, 2, 3,…, etc.).

According to negative supply function; increasing product (crop) supply decreases its price. Thus, the quantity of production for agricultural activities per unit (Q) can be obtained from the following function:

$Q_n = P_n \times A_n$ …………………....(2)

Where,

P : is the productivity of the agricultural activities suggested by the model.

A : is the cultivated area of the agricultural activities suggested by the model.

$n's$: are the agricultural activities of the suggested model (1, 2, 3,…, etc.).

For obtaining net revenues of the agricultural activities suggested by the model, equation (2) is used to resolve equation (1). Thus, the equation can be written as following:

$Y_n = (Q_n \times X_n) - C_n$ …………...(3)

$X_n = a + bQ_n = a + b(P_n \times A_n)$

Where,

Y : is the net revenue of the agricultural activities suggested by the model.

C : are the production costs of the agricultural activities suggested by the model.

$n's$: are the agricultural activities of the suggested model (1, 2, 3,…, etc.).

The objective function can be maximized as following:

$Maxf = Y_n \times \sum_{i=1}^{n} A_n$ ……......(4)

Where,

Y : is the net revenue computed by the model.

A : is the cultivated area computed by the model.

$n's$: are the agricultural activities of the suggested model (1, 2, 3,…, etc.).

The constraints of this model concerned with water requirements of the agricultural activities suggested by the model are as following:

1- Irrigation water (groundwater): $\text{Available Groundwater} \leq G_n \times \sum_{i=1}^{n} A_n$

2- Cultivated area: $\text{Total Cultivated Area} \leq \sum_{i=1}^{n} A_n$

G : is the available groundwater for the agricultural activities suggested by the model.

A : is the cultivated area for the agricultural activities suggested by the model.

$n's$: are the agricultural activities of the suggested model (1, 2, 3,…, etc.).

3. Results and Discussion

3.1. Land Resources

Egypt, covering approximately one million squared kilometers of land is geographically divided into four main divisions (ICP, 2003):

3.1.1. The Nile Valley & Delta, which covers an area of about 40 thousand square kilometers (9.5 million feddans), representing 4.0% of Egypt's land surface. The Nile Valley covers an area of 11 thousand square kilometers. The Nile Delta covers an area of about 29 thousand square kilometers.

3.1.2. The Western Desert, which covers an area of about 681 thousand square kilometers (162.1 million feddans), representing 68.1% of Egypt's land surface. This immense desert to the west of the Nile spans the area from the Mediterranean Sea south to the Sudanese border. This region is the driest one in Egypt. It is famous for winds. This region consists of three plateaus, separated by two depressions:

a. The Nubian Plateau, where the Nubian Sandstone Aquifer System (NSAS) extends below. Dakhla and Kharga Depressions are located in this Plateau.

b. The Middle Plateau, where Farafra and Baharyia Depressions are located.

C. The Northern Plateau, where Wadi El Natrun and Qattara Depressions and Siwa Oasis are located.

3.1.3. The Eastern Desert, which covers an area of about 223 thousand square kilometers (53.1 million feddans), representing 22.3% of Egypt’s land surface.

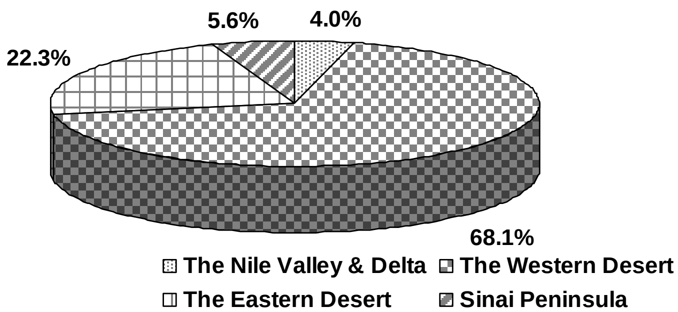
3.1.4. Sinai Peninsula, which covers an area of about 56 thousand square kilometers (13.3 million feddans), representing 5.6% of Egypt's land surface as shown in table (1) and represented in figure (1).

Table (1): Egypt's land surface area.

District	Area (thousand square kilometers)	Area (million feddans)	% of Egypt's land surface
The Nile Valley & Delta	40.0	9.5	4.0
The Western Desert	681.0	162.1	68.1
The Eastern Desert	223.0	53.1	22.3
Sinai Peninsula	56.0	13.3	5.6
Total area	1000.0	238.1	100.0

Source: INP, 2003.

Figure (1): Egypt's land surface area (million feddans).

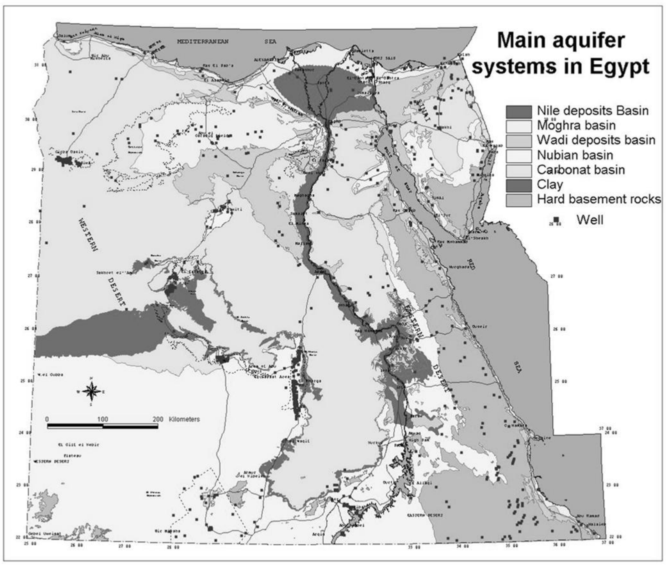


Source: compiled and computed from table (1).

3.2. Groundwater Resources

Groundwater in Egypt is found virtually everywhere in the sandy and gravely layers (aquifers) underneath the Nile flood surface and the nearby desert areas. Egypt's groundwater aquifers are located underground the Western Desert, Northern Sinai, Eastern Desert and Southern Sinai. Figure (2) locates aquifers within the geographic regions of the country, (Attia, 2003).

Figure (2): Surface distribution of aquifer system.



Source: Fatma A. Attia, 2003.

As shown in table (2), the annual discharge of East Ewainat aquifer is estimated at 1.5 B.C.M. meanwhile, the annual discharge of New Valley aquifer is estimated at 1.0 B.C.M. and the annual discharge of Sinai aquifer is estimated at 0.5 B.C.M. Thus, the annual total discharge of the non-renewable groundwater is 3.0 B.C.M. In addition to 1.0 B.C.M. of renewable groundwater which is recharged by seasonal rainfall on the Northern coast. Therefore, Egypt's total annual of groundwater is 4.0 B.C.M.

Studies of desert groundwater proved that the daily discharge of East Ewainat aquifer is 4.7 million cubic meters (M.C.M.) and the discharge of this aquifer is 150.0 B.C.M. to be extracted in the long term (about a hundred of years). This amount is adequate for irrigating approximately 189.6 thousand feddans. Meanwhile, the daily discharge of New Valley aquifer is 3.1 M.C.M. and the discharge of this aquifer is 100.0 B.C.M. to be extracted in the long term. This amount is adequate for irrigating approximately 133.3 thousand feddans. The daily discharge of Sinai aquifer is 1.6 M.C.M. and the discharge of Sinai aquifer is 50.0 B.C.M. to be extracted in the long term. This amount is adequate for irrigating approximately 66.7 thousand feddans. Thus, the daily discharge of non-renewable groundwater is 9.4 M.C.M. and the discharge of non-renewable groundwater is 300.0 B.C.M. to be extracted in the long term. This amount is adequate for irrigating approximately 389.6 thousand feddans, (El Baz, 1998).

However, the daily discharge of renewable groundwater is 3.6 M.C.M. and the discharge of renewable groundwater is 100.0 B.C.M. to be extracted in the long term. This amount is adequate for irrigating approximately 143.7 thousand feddans.

The total daily discharge of groundwater is 13.0 M.C.M. and the total discharge of groundwater is 400.0 B.C.M. to be extracted in the long term. This amount is adequate for irrigating an area estimated at approximately 533.3 thousand feddans, (MWRI, Ministry Plan till 2017).

Table (2): Available groundwater resources in the Egyptian deserts.

District	Daily discharge (M.C.M.)	Annual discharge (B.C.M.)	Discharge in the long term (B.C.M.)	Annual Irrigated area (thousand feddans)
East Ewainat	4.7	1.5	150.0	189.6
New Valley	3.1	1.0	100.0	133.3
Sinai	1.6	0.5	50.0	66.7
Total of Non-renewable Groundwater	9.4	3.0	300.0	389.6
Renewable Groundwater	3.6	1.0	100.0	143.7
Total	13.0	4.0	400.0	533.3

Source: Ministry of Water Resources and Irrigation, Ministry Plan till 2017, Cairo.

3.3. The optimum cropping patterns

The selection of a certain crop to be cultivated in a certain area depends on several factors; weather, soil type, water resources, water consumption … etc.

According to these factors together with the results of agricultural experiments occurred in the Western Desert, Sinai and East Ewainat, the present study suggests the following crops to be cultivated (DRC, 1999):

3.3.1. Fruit Trees: date palms, olive, seed orange, sweet lemon, salt lemon, pomegranate, mango, apricot, grapes and American fig.

3.3.2. Crops: wheat, barley, lentil, broad bean, berseem, alfalfa, sunflower, rape seed (canola), peanut, sugar beet, cotton, sorghum, elephant fodder and millet.

3.3.3. Vegetables: tomato, potato, sweet potato, pea, artichoke, cucumber, okra, green bean, pepper, garlic, cucurbits and some exportable vegetables that have comparative advantages.

3.3.4. Aromatic and Medical Plants: hibiscus, red chilies, cumin, coriander, fennel, anise, spear mint, aromatic, lemon grass, daturine, hemlock, senna, moghat, caster bean, pepper, basil, fenugreek, yucca, gladiolas and some exportable medical plants.

Thus, nine scenarios of cropping patterns in different crop rotations specialized in producing certain crops are suggested. These scenarios are discussed in the following section.

(1) Cotton Crop Rotation:

First Year	Second Year	Third Year
Short Clover+Cotton	Wheat+Pepper	Tomato+Millet
Tomato+Millet	Short Clover+Cotton	Wheat+Pepper
Wheat+Pepper	Tomato+Millet	Short Clover+Cotton

As shown in table (3), the average productivity in this crop rotation is 23.98 ton/feddan, however, the average costs is L.E. 2762 per feddan, meanwhile, the average return is L.E. 5787 per feddan, moreover, the average revenue is L.E. 3025 per feddan, in addition, the average water consumption is 7350 C.M./feddan, furthermore, the average water productivity is 3.26 Kg/C.M. and the average water profitability is L.E. 0.41 per C.M. as presented in table (3).

Table (3): Average productivity, costs, revenue, gross margin, water consumption, and water productivity and profitability for cotton crop rotation.

Item	Short Clover +Cotton	Tomato +Millet	Wheat +Pepper	Average
Productivity (Ton per feddan)	6.47	54.09	11.40	23.98
Costs (L.E. per feddan)	1783.00	3954.00	2548.00	2762.00
Revenue (L.E. per feddan)	3177.00	9599.00	4585.00	5787.00
Gross margin (L.E. per feddan)	1394.00	5645.00	2037.00	3025.00
Water consumption (C.M. per feddan)	7457.00	7382.00	7249.00	7350.00
Water productivity (Kg per C.M.)	0.87	7.33	1.57	3.26
Water profitability (L.E. per C.M.)	0.19	0.76	0.28	0.41

Source: Desert Research Center (DRC), Suggested Cropping Pattern Models in New Lands, Vol. 3, 1999.

(2) Food Oil Crop Rotation:

First Year	Second Year	Third Year
Broad Bean+Soya Bean	Tomato+Sunflower	Canola+Water Melon
Canola+Water Melon	Broad Bean+Soya Bean	Tomato+Sunflower
Tomato+Sunflower	Canola+Water Melon	Broad Bean+Soya Bean

This crop rotation lasts for four years. Crops are rotated together with cattle rising to improve soil fertility. As shown in table (4), the average productivity in this crop rotation is 12.60 ton/feddan, in addition, the average costs is L.E. 2235 per feddan, furthermore, the average revenue is L.E. 4387 per feddan, however, the average gross margin is L.E. 2168 per feddan, meanwhile, the average water consumption is 6586 C.M./feddan, moreover, the average water productivity is 1.91 Kg/C.M. and the average water profitability is L.E. 0.33 per C.M.

Table (4): Average productivity, costs, revenue, gross margin, water consumption, and water productivity and profitability for food oil crop rotation.

Item	Broad Bean +Soya Bean	Canola +Water Melon	Tomato +Sunflower	Average
Productivity (Ton per feddan)	4.04	11.59	22.16	12.60
Costs (L.E. per feddan)	2100.00	1835.00	2769.00	2235.00
Revenue (L.E. per feddan)	3673.00	3464.00	6028.00	4387.00
Gross margin (L.E. per feddan)	1573.00	1629.00	3259.00	2168.00
Water consumption (C.M. per feddan)	6467.00	5826.00	7464.00	6586.00
Water productivity (Kg per C.M.)	0.62	1.99	2.97	1.91
Water profitability (L.E. per C.M.)	0.24	0.28	0.44	0.33

Source: Desert Research Center (DRC), Suggested Cropping Pattern Models in New Lands, Vol. 3, 1999.

(3) Fodders Crop Rotation:

First Year	Second Year	Third Year
Berseem+Sorghum	Tomato+Millet	Broad Bean+Sweet Sorghum
Tomato+Millet	Broad Bean+Sweet Sorghum	Berseem+Sorghum
Broad Bean+Sweet Sorghum	Berseem+Sorghum	Tomato+Millet

Table (5): Average Productivity, Costs, Revenue, Gross margin As shown in table (5), The average productivity in this crop rotation is 30.80 ton/feddan, however, the average costs is L.E. 2120 per feddan, in addition, the average revenue is L.E. 6990 per feddan, furthermore, the average gross margin is L.E. 4870 per feddan, meanwhile, the average water consumption is 7421 C.M./feddan, moreover, the average water productivity is 4.15 Kg/C.M. and the average water profitability is L.E. 0.66 per C.M.

Table (5): Average productivity, costs, revenue, gross margin, water consumption, and water productivity and profitability for fodders crop rotation.

Item	Berseem +Sorghum	Tomato +Millet	Broad Bean +Sweet Sorghum	Average
Productivity (Ton per feddan)	8.45	54.09	29.90	30.80
Costs (L.E. per feddan)	1545.00	3954.00	1885.00	2120.00
Revenue (L.E. per feddan)	4957.00	9599.00	6560.00	6990.00
Gross margin (L.E. per feddan)	3412.00	6525.00	4675.00	4870.00
Water consumption (C.M. per feddan)	7500.00	7382.00	7499.00	7421.00
Water productivity (Kg per C.M.)	1.13	7.33	3.99	4.15
Water profitability (L.E. per C.M.)	0.45	0.76	0.62	0.66

Source: Desert Research Center (DRC), Suggested Cropping Pattern Models in New Lands, Vol. 3, 1999.

(4) Aromatic & Medical Plants Crop Rotation:

First Year	Second Year	Third Year
Visnaga+Water Melon	Hemlock+Millet	Berseem+Red Chilies
Berseem+Red Chilies	Visnaga+Water Melon	Hemlock+Millet
Hemlock+Millet	Berseem+Red Chilies	Visnaga+Water Melon

As shown in table (6), The average productivity in this crop rotation is 19.17 ton/feddan, meanwhile, the average costs is L.E. 1845 per feddan, however, the average revenue is L.E. 5098 per feddan, furthermore, the average gross margin is L.E. 3254 per feddan, moreover, the average water consumption is 6680 C.M./feddan, in addition, the average water productivity is 2.87 Kg/C.M. and the average water profitability is L.E. 0.94 per C.M.

Table (6): Average productivity, costs, revenue, gross margin, water consumption, and water productivity and profitability for aromatic & medical plants crop rotation.

Item	Visnaga +Water Melon	Berseem +Red Chilies	Hemlock +Millet	Average
Productivity (Ton per feddan)	11.40	10.58	36.07	19.17
Costs (L.E. per feddan)	1638.00	2164.00	1732.00	1845.00
Revenue (L.E. per feddan)	7470.00	4343.00	3481.00	5098.00
Gross margin (L.E. per feddan)	5832.00	2179.00	1749.00	3254.00
Water consumption (C.M. per feddan)	5094.00	7500.00	7450.00	6680.00
Water productivity (Kg per C.M.)	1.95	1.41	4.84	2.87
Water profitability (L.E. per C.M.)	1.14	0.29	0.23	0.94

Source: Desert Research Center (DRC), Suggested Cropping Pattern Models in New Lands, Vol. 3, 1999.

(5) Date Palms (dried and semi dried)+Alfalfa in between Crop Rotation:

The average productivity in this crop rotation is 45.57 ton/feddan, however, the average costs is L.E. 2046 per feddan, in addition, the average revenue is L.E. 9446 per feddan, furthermore, the average gross margin is L.E. 7400 per feddan, meanwhile, the average water consumption is 7453 C.M./feddan, moreover, the average groundwater productivity is 6.11 Kg/C.M. and the average water profitability is L.E. 0.99 per C.M.

(6) Olive+Alfalfa in between Crop Rotation:

The average productivity in this crop rotation is 39.62 ton/feddan, however, the average costs is L.E. 2326 per feddan, meanwhile, the average revenue is L.E. 9946 per feddan, moreover, the average gross margin is L.E. 7620 per feddan, in addition, the average water consumption is 7453 C.M./feddan, furthermore, the average groundwater productivity is 5.32 Kg/C.M. and the average water profitability is L.E. 1.02 per C.M.

(7) Permanent Ornamental Plants and Fodders Crop Rotation:

The First Five Years	The Following Five Years
Swallow	Alfalfa
Alfalfa	Swallow

The average productivity in this crop rotation is 38.65 ton/feddan, however, the average costs is L.E. 6526 per feddan, furthermore, the average revenue is L.E. 19250 per feddan, in addition, the average gross margin is L.E. 12724 per feddan, meanwhile, the average water consumption is 7320 C.M./feddan, moreover, the average groundwater productivity is 5.28 Kg/C.M. and the average water profitability is L.E. 1.74 per C.M.

(8) Ornamental Flowers Crop Rotation:

First Year	Second Year	Third Year
Berseem+Pepper	yucca+Water Melon	Gladiolas+Sunflower
Gladiolas+Sunflower	Berseem+Pepper	yucca+Water Melon
yucca+Water Melon	Gladiolas+Sunflower	Berseem+Pepper

As shown in table (7), the average productivity in this crop rotation is 8.95 ton/feddan, in addition, the average costs is L.E. 4843 per feddan, furthermore, the average revenue is L.E. 11225 per feddan, however, the average gross margin is L.E. 6382 per feddan, meanwhile, the average water consumption is 7210 C.M./feddan, moreover, the average water productivity is 1.24 Kg/C.M. and the average water profitability is L.E. 0.88 per C.M.

Table (7): Average productivity, costs, revenue, gross margin, water consumption, and water productivity and profitability for ornamental flowers crop rotation.

Item	Berseem +Pepper	Gladiolas +Sunflower	Yucca +Water Melon	Average
Productivity (Ton per feddan)	10.33	3.52	13.00	8.95
Costs (L.E. per feddan)	2164.00	6176.00	6188.00	4843.00
Revenue (L.E. per feddan)	4452.00	13122.00	16101.00	11225.00
Gross margin (L.E. per feddan)	2288.00	6946.00	9913.00	6382.00
Water consumption (C.M. per feddan)	7500.00	7257.00	6088.00	7210.00
Water productivity (Kg per C.M.)	1.38	0.48	2.13	1.24
Water profitability (L.E. per C.M.)	0.30	0.96	1.63	0.88

Source: Desert Research Center (DRC), Suggested Cropping Pattern Models in New Lands, Vol. 3, 1999.

(9) Rose Crop Rotation:

The average productivity of this crop rotation is 2.27 ton/feddan, in addition, the average costs is L.E. 7000 per feddan, furthermore, the average revenue is L.E. 13500 per feddan, however, the average gross margin is L.E. 6500 per feddan, meanwhile, the average water consumption is 5362 C.M./feddan, moreover, the average groundwater productivity is 0.42 Kg/C.M. and the average water profitability is L.E. 1.21 per C.M.

As indicated in table (8), among the previous crop rotations, Permanent Ornamental Plants and Fodders crop rotation ranks first with respect to the highest net revenue, estimated at L.E. 12724 per feddan. Olive+Alfalfa crop rotation ranks the second with respect to the highest net revenue, estimated at L.E. 7620 per feddan. Date Palms+Alfalfa crop rotation ranks the third with respect to the highest net revenue, estimated at L.E. 7400 per feddan.

Table (8): Average gross margin, water consumption, water productivity and profitability for different crop rotations.

Crop rotations	Gross margin (L.E./feddan)	Water consumption (C.M./feddan)	Water productivity (Kg/C.M.)	Water profitability (L.E./C.M.)
Cotton	3025.00	7350.00	3.26	0.41
Food Oil	2168.00	6586.00	1.91	0.33
Fodders	4870.00	7421.00	4.15	0.66
Aromatic & Medical Plants	3254.00	6680.00	2.87	0.94
Date Palms+Alfalfa	7400.00	7453.00	6.11	0.99
Olive+Alfalfa	7620.00	7453.00	5.32	1.02
Permanent Ornamental Plants and fodders	12724.00	7320.00	5.28	1.74
Ornamental Flowers	6382.00	7210.00	1.24	0.88
Rose Productivity	6500.00	5362.00	0.42	1.21

Source: compiled and computed from the previous crop rotations.

However, among the previous crop rotations, rose crop rotation ranks the first with respect to the least groundwater consumption, estimated at 5362 C.M./feddan. Food oil crop rotation ranks the second with respect to the least groundwater consumption, estimated at 6586 C.M./feddan. Aromatic and medical plants crop rotation ranks the third with respect to the least groundwater consumption, estimated at 6680 C.M./feddan.

Among the previous crop rotations, Permanent Ornamental Plants and Fodders crop rotation ranks the first with respect to the highest water profitability, estimated at L.E. 1.74 per C.M. rose crop rotation ranks the second with respect to the highest water profitability, estimated at L.E. 1.21 per C.M. and Olive+Alfalfa crop rotation ranks the third with respect to the highest water profitability, estimated at L.E. 1.02 per C.M.

3.4. The suggested cropping patterns for desert lands and groundwater requirements

This study suggests five models of cropping patterns suitable for desert environmental circumstances as following:

Model	% of the Area	Crops
The First	50%	Fruits+Date Palms (Dried & Semi Dried)
	50%	Winter: 25% Cereals+25% Vegetables+25% Fodders+25% Oil Crops
		Summer: 25% Cereals+25% Vegetables+25% Fodders+25% Uncultivated Area
The Second	40%	Fruits+Date Palms (Dried & Semi Dried)
	60%	Winter: 25% Cereals+25% Vegetables+25% Fodders+25% Oil Crops
		Summer: 25% Cereals+25% Vegetables+15% Fodders+10% Oil Crops+25% Uncultivated Area
The Third	30%	Fruits+Date Palms (Dried & Semi Dried)
	70%	Winter: 25% Cereals+25% Vegetables+25% Fodders+25% Oil Crops
		Summer: 25% Cereals+25% Vegetables+15% Fodders+10% Seasonings+25% Uncultivated Area
The Fourth	25%	Fruits+Date Palms (Dried & Semi Dried)
	75%	Winter: 25% Cereals+25% Vegetables+25% Fodders+25% Oil Crops
		Summer: 25% Cereals+25% Vegetables+15% Fodders+10% Medical Plants+25% Uncultivated Area
The Fifth	20%	Fruits+Date Palms (Dried & Semi Dried)
	80%	Winter: 25% Cereals+25% Vegetables+25% Fodders+25% Oil Crops
		Summer: 25% Cereals+25% Vegetables+15% Fodders+10% Medical Plants+25% Uncultivated Area

The results of the model for the suggested cropping patterns for desert lands are shown in tables (9), (10), (11) and (12) and represented in figures (3), (4) and (5).

3.4.1. The suggested cropping pattern obtained by the first model:

The total suggested cropping area is estimated at 220 thousand feddans, a half of this area is completely cultivated by fruits and date palms and the rest area is cultivated by cereals, vegetables, fodders and oil crops in winter. Meanwhile, in the summer 75.0% of this area is cultivated by cereals, vegetables and fodders, leaving 25.0% as an uncultivated area.

The average water consumption for the cropping pattern obtained by this model is estimated at 1546 M.C.M. annually. Water consumption for fruits is estimated at 825 M.C.M. Meanwhile, water consumption for winter season crops is estimated at 412 M.C.M, representing 26.6% of the available irrigation groundwater for the cropping pattern obtained by this model. However, water consumption for summer season crops is estimated at 309 M.C.M, representing 20.0% of the available irrigation groundwater for the cropping pattern obtained by this model. In addition, the average of net revenue for the cropping pattern obtained by this model is estimated at L.E. 3350.

3.4.2. The suggested cropping pattern obtained by the second model:

The total suggested cropping area is estimated at 264 thousand feddans of which 40.0% is completely cultivated by fruits and date palms and the rest area is cultivated by cereals, vegetables, fodders and oil crops in winter. Meanwhile, in the summer 75.0% of this area is cultivated by cereals, vegetables and fodders, leaving 25.0% as an uncultivated area.

The average water consumption for the cropping pattern obtained by this model is estimated at 1831 M.C.M. annually. Water consumption for fruits is estimated at 792 M.C.M. Meanwhile, water consumption for winter season crops is estimated at 594 M.C.M, representing 32.4% of the available irrigation groundwater for the cropping pattern obtained by this model. However, water consumption for summer season crops is estimated at 445 M.C.M, representing 24.3% of the available irrigation groundwater for the cropping pattern obtained by this model. In addition, the average of net revenue for the cropping pattern obtained by this model is estimated at L.E. 3127.

3.4.3. The suggested cropping pattern obtained by the third model:

The total suggested cropping area is estimated at 317 thousand feddans of which 30.0% is completely cultivated by fruits and date palms and the rest area is cultivated by cereals, vegetables, fodders and oil crops in winter. Meanwhile, in the summer 75.0% of this area is cultivated by cereals, vegetables, fodders and seasonings, leaving 25.0% as an uncultivated area.

The average water consumption for the cropping pattern obtained by this model is estimated at 2169 M.C.M. annually. Water consumption for fruits is estimated at 713 M.C.M. Meanwhile, water consumption for winter season crops is estimated at 832 M.C.M, representing 38.3% of the available irrigation groundwater for the cropping pattern obtained by this model. However, water consumption for summer season crops is estimated at 624 M.C.M, representing 28.8% of the available irrigation groundwater for the cropping pattern obtained by this model. In addition, the average of net revenue for the cropping pattern obtained by this model is estimated at L.E. 4252.

3.4.4. The suggested cropping pattern obtained by the fourth model:

The total suggested cropping area is estimated at 380 thousand feddans of which 25.0% is completely cultivated by fruits and date palms and the rest area is cultivated by cereals, vegetables, fodders and oil crops in winter. Meanwhile, in the summer 75.0% of this area is cultivated by cereals, vegetables, fodders and medical plants, leaving 25.0% as an uncultivated area.

The average water consumption for the cropping pattern obtained by this model is estimated at 2586 M.C.M. annually. Water consumption for fruits is estimated at 712 M.C.M. Meanwhile, water consumption for winter season crops is estimated at 1071 M.C.M, representing 41.4% of the available irrigation groundwater for the cropping pattern obtained by this model. However, water consumption for summer season crops is estimated at 803 M.C.M, representing 31.0% of the available irrigation groundwater for the cropping pattern obtained by this model. In addition, the average of net revenue for the cropping pattern obtained by this model is estimated at L.E. 4105.

3.4.5. The suggested cropping pattern obtained by the fifth model:

The total suggested cropping area is estimated at thousand feddans of which 20.0% is completely cultivated by fruits and date palms and the rest area is cultivated by cereals, vegetables, fodders and oil crops in winter. Meanwhile, in the summer 75.0% of this area is cultivated by cereals, vegetables, fodders and medical plants, leaving 25.0% as an uncultivated area.

The average water consumption for the cropping pattern obtained by this model is estimated at 3597 M.C.M. annually. Water consumption for fruits is estimated at 799.5 M.C.M. Meanwhile, water consumption for winter season crops is estimated at 1599 M.C.M, representing 44.4% of the available irrigation groundwater for the cropping pattern obtained by this model. However, water consumption for summer season crops is estimated at 1198.5 M.C.M, representing 33.4% of the available irrigation groundwater for the cropping pattern obtained by this model. In addition, the average of net revenue for the cropping pattern obtained by this model is estimated at L.E. 3963.

As indicated in table (9) and represented in figure (3), the cultivated area in the cropping pattern suggested by the first model is estimated at approximately 220 thousand feddans. However, the cultivated area in the second model is estimated at approximately 264 thousand feddans, representing an increase of 20%. The cultivated area in the third model is estimated at approximately 317 thousand feddans, representing an increase of 20%. Meanwhile, the cultivated area in the fourth model is estimated at approximately 380 thousand feddans, representing an increase of 20%, whereas the cultivated area in the fifth model is estimated at approximately 533 thousand feddans, representing an increase of 20%, reaching the maximum of cultivated irrigated by the available groundwater resources in the long term.

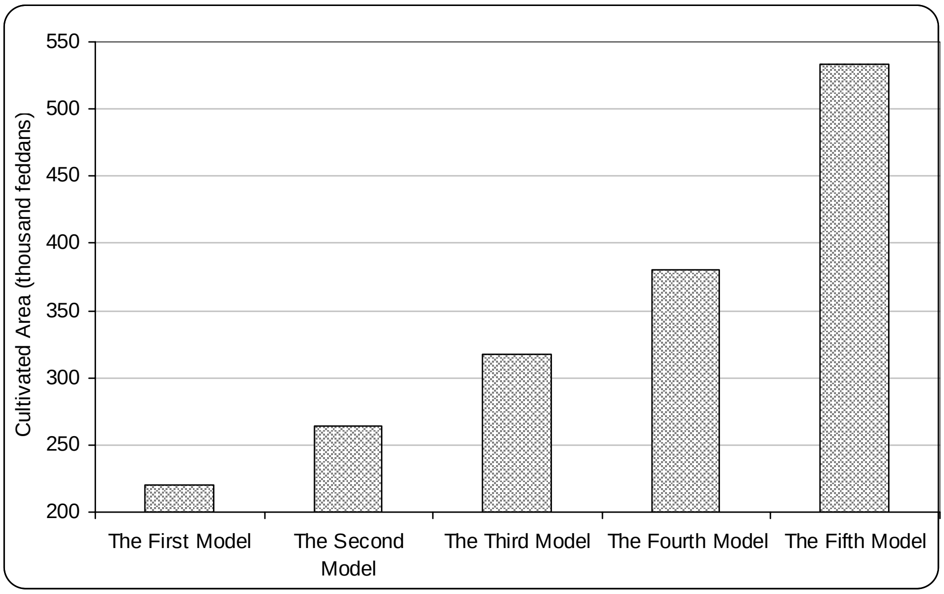
Table (9) shows that, the areas cultivated by fruits and date palms in the cropping pattern suggested by the five models vary from 95 thousand feddans in the third model to 110 thousand feddans in the first model. It is also noticed that winter-season area is completely cultivated by cereals, vegetables, fodders and oil crops. Meanwhile, 75.0% of the summer-season area is cultivated by cereals, vegetables, fodders and oil crops or seasonings or medical plants, leaving 25.0% as an uncultivated area, thus saving groundwater to tolerate high temperature in the deserts during the summer.

Table (9): A comparison between cultivated areas in desert lands according to different suggested cropping patterns (thousand feddan).

Crop	The First Model	The Second Model	The Third Model	The Fourth Model	The Fifth Model
Fruits & Date Palms	110.00	105.60	95.00	95.00	106.60
Winter Cereals	27.50	39.60	55.50	71.40	106.60
Summer Cereals	27.50	39.60	55.50	71.30	106.60
Winter Vegetables	27.50	39.60	55.50	71.20	106.60
Summer Vegetables	27.50	39.60	55.50	71.30	106.60
Winter Fodders	27.50	39.60	55.50	71.20	106.60
Summer Fodders	27.50	23.80	33.30	42.60	64.00
Winter Oil Crops	27.50	39.60	55.50	71.20	106.60
Summer Oil Crops	-	15.80	-	-	-
Medical Plants	-	-	-	28.50	42.60
Seasonings	-	-	22.20	-	-
Uncultivated	27.50	39.60	55.50	71.30	106.60
Total	220.00	264.00	317.00	380.00	533.00

Source: compiled and computed from the cropping pattern obtained from the model.

Figure (3): A comparison between cultivated areas according to different suggested cropping patterns.



Source: compiled and computed from table (9).

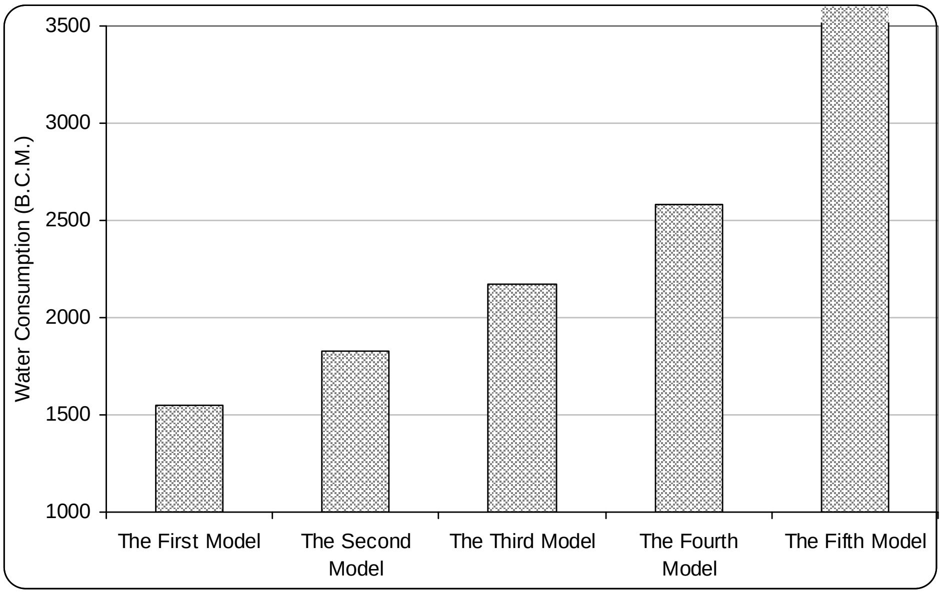
As shown in table (10) and represented in figure (4), the average groundwater consumption for the cropping pattern suggested by the first model is estimated at approximately 1.546 B.C.M., representing 38.6% of the available groundwater resources in the long term estimated at approximately 4.000 B.C.M annually. However, the average groundwater consumption for the second model is estimated at approximately 1.831 B.C.M., representing 45.8% of the available groundwater resources in the long term. The average groundwater consumption for the third model is estimated at approximately 2.169 B.C.M., representing 54.2% of the available groundwater resources in the long term. Meanwhile, the average groundwater consumption for the fourth model is estimated at approximately 2.586 B.C.M., representing 64.5% of the available groundwater resources in the long term, whereas the cultivated area for the fifth model is estimated at approximately 3.597 B.C.M., representing 89.9% of the available groundwater resources in the long term. The results are briefly described below and are summarized in Table (11).

Table (10): A comparison between the average of water consumption according to different suggested cropping patterns (M.C.M.).

Crop	The First Model	The Second Model	The Third Model	The Fourth Model	The Fifth Model
Fruits & Date Palms	825.00	792.00	713.00	712.00	799.50
Winter Cereals	103.00	148.50	208.00	268.00	399.75
Summer Cereals	103.00	148.50	208.00	267.00	399.75
Winter Vegetables	103.00	148.50	208.00	268.00	399.75
Summer Vegetables	103.00	148.50	208.00	267.00	399.75
Winter Fodders	103.00	148.50	208.00	267.00	399.75
Summer Fodders	103.00	89.00	125.00	162.00	240.00
Winter Oil Crops	103.00	148.50	208.00	268.00	399.75
Summer Oil Crops	-	59.00	-	-	-
Medical Plants	-	-	-	107.00	159.00
Seasonings	-	-	83.00	-	-
Total	1546.00	1831.00	2169.00	2586.00	3597.00

Source: compiled and computed from the cropping pattern obtained from the model.

Figure (4): A comparison between water consumption according to different suggested cropping patterns.



Source: compiled and computed from table (10).

Table (11): Cultivated area and the average of groundwater consumption for crops according to different suggested cropping patterns.

	Crop	The First Model	The Second Model	The Third Model	The Fourth Model	The Fifth Model
Cultivated Area (Thousand Feddans)	Fruits & Date Palms	110.00	105.60	95.00	95.00	106.60
	Winter Crops	110.00	158.40	222.00	285.00	426.40
	Summer Crops	82.50	118.80	166.50	213.70	319.80
	Uncultivated Area	27.50	39.60	55.50	71.30	106.60
Cropped Area (Thousand Feddans)		220.00	264.00	317.00	380.00	533.00
Average Groundwater Consumption (M.C.M.)	Fruits & Date Palms	825.00	792.00	713.00	712.00	799.50
	Winter Crops	412.00	594.00	832.00	1071.00	1599.00
	Summer Crops	309.00	445.00	624.00	803.00	1198.50
	Total	1546.00	1831.00	2169.00	2586.00	3597.00

Source: compiled and computed from tables (9) and (10).

As indicated in table (12) and represented in figure (5), among the previous the cropping patterns obtained by the five models, the third model ranks first with respect to the highest average of net revenue, estimated at approximately L.E. 4252 per feddan. The fourth model ranks the second with respect to the highest average of net revenue, estimated at approximately L.E. 4105 per feddan, representing a decrease of 3.9% out of the highest average of net revenue. The fifth model ranks the third with respect to the highest net revenue, estimated at approximately L.E. 3963 per feddan, representing a decrease of 7.3% out of the highest average of net revenue. The first model ranks the fourth with respect to the highest net revenue, estimated at approximately L.E. 3350 per feddan, representing a decrease of 26.9% out of the highest average of net revenue. The second model ranks the fifth with respect to the highest net revenue, estimated at approximately L.E. 3127 per feddan, representing a decrease of 36.0% out of the highest average of net revenue.

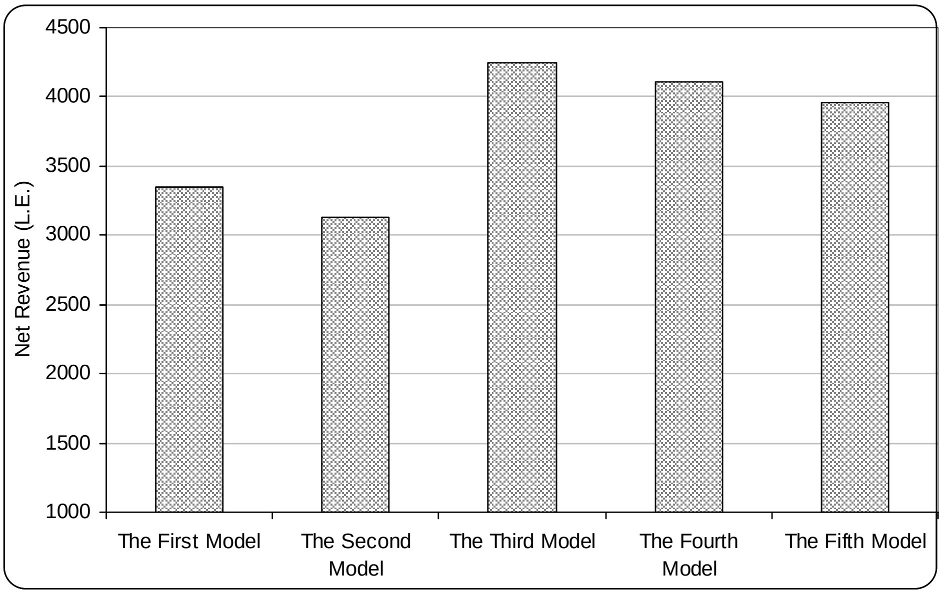
Table (12) shows that for fruits and date palms, the average of net revenue obtained by the third model ranks first with an average of L.E. 9863 per feddan, followed by that of the fourth model with an average of L.E. 8889 per feddan. For winter cereals, the average of net revenue obtained by the fourth model ranks first with an average of L.E. 1000 per feddan, followed by that of the fifth model with an average of L.E. 912 per feddan. For summer cereals, the average of net revenue obtained by the third model ranks first with an average of L.E. 511 per feddan, followed by that of the second model with an average of L.E. 425 per feddan. For winter vegetables, the average of net revenue obtained by the fifth model ranks first with an average of L.E. 6456 per feddan, followed by that of the third model with an average of L.E. 6318 per feddan. For summer vegetables, the average of net revenue obtained by the fifth model ranks first with an average of L.E. 8288 per feddan, followed by that of the third model with an average of L.E. 8123 per feddan. For winter fodders, the average of net revenue obtained by the fourth model ranks first with an average of L.E. 2410 per feddan, followed by that of the fifth model with an average of L.E. 2289 per feddan. For summer fodders, the average of net revenue obtained by the fourth model ranks first with an average of L.E. 1989 per feddan, followed by that of the second model with an average of L.E. 1721 per feddan. For winter oil crops, the average of net revenue obtained by the first model ranks first with an average of L.E. 1609 per feddan, followed by that of the second model with an average of L.E. 1524 per feddan.

Table (12): A comparison between the average of net revenues according to different suggested cropping patterns (L.E.).

Crop	The First Model	The Second Model	The Third Model	The Fourth Model	The Fifth Model
Fruits & Date Palms	6835.00	7440.00	9863.00	8889.00	7652.00
Winter Cereals	853.00	799.00	827.00	1000.00	912.00
Summer Cereals	368.00	425.00	511.00	416.00	395.00
Winter Vegetables	6225.00	5851.00	6318.00	5974.00	6456.00
Summer Vegetables	7538.00	7295.00	8123.00	7831.00	8288.00
Winter Fodders	2154.00	2096.00	2235.00	2410.00	2289.00
Summer Fodders	1229.00	1721.00	1325.00	1989.00	1222.00
Winter Oil Crops	1609.00	1524.00	1449.00	1218.00	1197.00
Summer Oil Crops	-	990.00	-	-	-
Medical Plants	-	-	-	7215.00	8450.00
Seasonings	-	-	7625.00	-	-
Average	3350.00	3127.00	4252.00	4105.00	3963.00

Source: compiled and computed from the cropping pattern obtained from the model.

Figure (5): A comparison between net revenues according to different suggested cropping patterns.

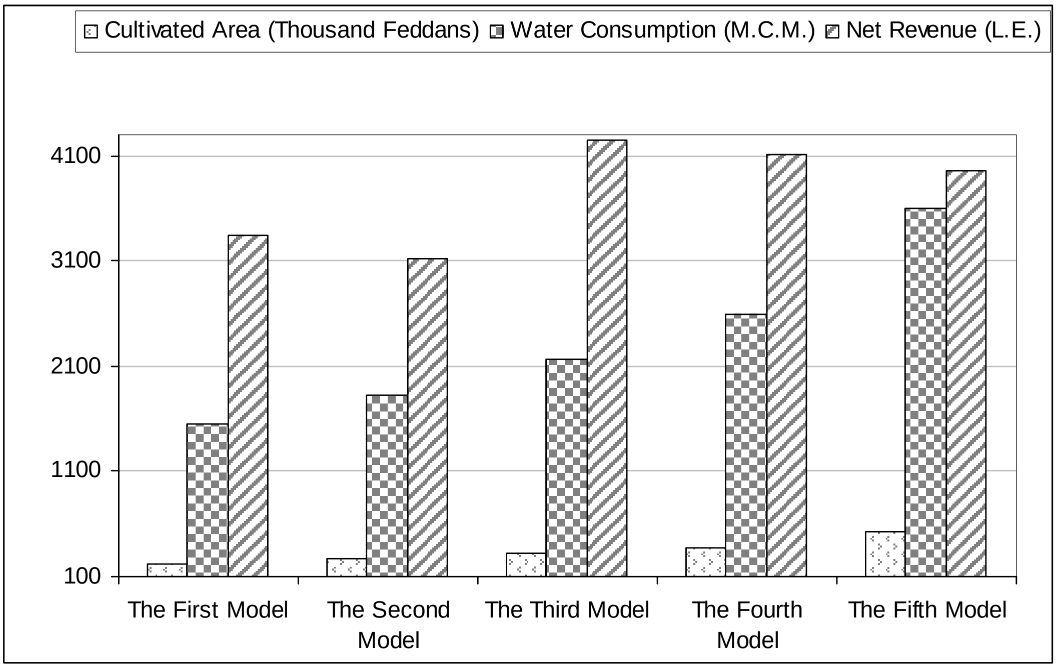


Source: compiled and computed from table (12).

On the light of these results, it can be concluded that among the cropping patterns obtained by the five models, the third model ranks first with respect to the highest average of net revenue, estimated at approximately L.E. 4252 per feddan, followed by that of the fourth model with an average of approximately L.E. 4105 per feddan. These two models save approximately 45.8% and 35.5% of the available groundwater resources in the long term respectively.

Although the first and the second models save approximately 61.4% and 54.2% of groundwater consumption respectively, these two models reduce the average of net revenue, estimated at approximately 26.9% and 36.0% out of the highest average of net revenue respectively as represented figure (6).

Figure (6): A comparison between the suggested cropping patterns in the five models.



<u>Source</u>: compiled and computed from tables (9), (10) and (12).

4. Concluding remarks, recommendations and policy implications

- More emphasis should be placed on the importance of selecting new strains and varieties of different crops that tolerate bad weather conditions. Besides, cultivating wind breakers.
- Water should be introduced in the economic accounting of the various agricultural uses. Hence, a system of cost recovery to maintain the irrigation system can be established.
- Establishing productivity stations in desert lands to make use of available groundwater.
- More effort should be directed to designing a cropping pattern map for Egypt according to specific crop rotations suitable for the available groundwater within its safe use so as to achieve efficient use of water irrigation.
- The scientific and technical capabilities of the integrated planning for sustainable and environmental sound use of groundwater should be enhanced.

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التراكيب المحصولية المناسبة للأراضي الصحراوية المصرية في ضوء محدودية المياه الجوفية

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تمثل الأراضي الصحراوية في مصر نسبة ٩٥% من إجمالي مساحة مصر ، ورغم ما يتم استصلاحه من أراضي جديدة ، إلا أن العائق في استصلاح الأراضي الصحراوية هو توفير المياه اللازمة للري ، وذلك نظراً لمحدودية الموارد المائية السطحية المتاحة والتي توفي بالكاد باحتياجات الأراضي المنزرعة حالياً ، الأمر الذي يستلزم البحث عن مصادر مائية أخرى كالمياه الجوفية لاستغلالها في زراعة الأراضي الصحراوية .

وتنطوي مشكلة البحث على أن استخدام الموارد المائية السطحية في عمليات التوسع الزراعي الأفقي خاصة في المناطق الصحراوية له مردود منخفض نسبياً بسبب ارتفاع تكلفة توصيل هذه مياه الري إلى تلك الأراضي ، فضلاً عن زراعة محاصيل لا تتناسب مع ذلك القدر المُتاح من الموارد المائية الاروائية ، مما يؤدي بدوره إلى انخفاض العائد من وحدة المياه المستخدمة. ويستهدف البحث دراسة عرض الموارد الأرضية والمائية الجوفية المتاحة في الصحارى المصرية ، وتحديد التراكيب المحصولية المناسبة في ظل المياه الجوفية المتاحة والتي تعظم صافي الدخل المتحقق من زراعة المحاصيل المختلفة في ظل التراكيب المحصولية المقترحة. وقد اعتمد البحث على أسلوب التحليل الوصفي والكمي وأسلوب البرمجة غير الخطية ، وتم التوصل إلى خمسة نماذج للتركيب المحصولي المناسب في الأراضي الصحراوية في ظل الموارد المائية الجوفية .

وأوضحت النتائج أن النموذج الثالث هو الأفضل يليه النموذج الرابع من حيث تعظيم صافي الدخل المتحقق والذي يُقدر بنحو ٤٢٥٢ و٤١٠٥ جنيه/فدان للنموذجين على التوالي ، وبالنظر إلى الوفر في الموارد المائية الجوفية ، فقد حقق هذين النموذجين وفراً في المياه الجوفية يُقدر بنحو ٨,٤٥% و٥,٣٥% من كمية المياه الجوفية المستخدمة على التوالي. وعلى الرغم من أن النموذج الأول والثاني قد حققا وفراً في كمية المياه الجوفية المستخدمة بنسبة ٤,٦١% و٢,٥٤% على التوالي ، إلا أنهما حققا صافي دخل أقل.'