MINIMIZATION OF WATER NEEDS IN IRAQI AGRICULTURE IN LIGHT OF THE PREVAILING CROPPING COMBINATION DURING

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ABSTRACT

The research aims to study the optimal allocation of irrigation water that is used to irrigate various agricultural crops at the level of Iraq. In order to achieve the goal of the research, two economic models were formulated according to the linear programming technique. The first model aimed to minimize the water needs of the prevailing crop combination during the average period (2017-2020), while the second model aimed to maximize the total profit margin of the water unit for the crop combination that minimizes the water needs during the same period. The first model was estimated with two proposed plans. The first proposed plan included non-imposing legislative restrictions related to the allocation of certain areas for basic agricultural crops that bias the food security requirements of the population, as well as crops that were recently banned from import by the Iraqi government, while the proposed second plan included the imposition and addition of restrictions of legislative areas that did not appear in the table of the optimal solution for the first plan. Results indicated that there is a surplus of water resource for the proposed economic plans according to the two estimated models, its quantity amounted to about 363.361, 9.178 million m3 for each plan, respectively, compared to the total amount of irrigation water needed for the current cropping combination, which was estimated at about 4.736726 billion m3 during the average mentioned period. Results of the analysis of the two estimated models also showed a preference for the results of plans with legislative restrictions as a result of the expansion in the cultivation of most basic and important crops and vegetables for local consumption.

Key words: water rationing, agricultural crops, optimal allocation, profit margin per unit of water, Iraq.

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تدنية الاحتياجات المائية بالزراعة العراقية في ظل التركيب المحصولي الراهن

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المستخلص

يستهدف البحث دراسة التخصيص الامثل لمياه الري المستخدمة في ارواء مختلف المحاصيل الزراعية على مستوى العراق. من اجل تحقيق هدف البحث تم صياغة نموذجين اقتصاديين على وفق تقنية البرمجة الخطية، استهدف النموذج الاول تدنية الاحتياجات المائية التركيب المحصولي السائد خلال متوسط المدة (2017 . 2020)، بينما استهدف النموذج الثاني تعظيم اجمالي هامش ربح وحدة المياه للتركيب المحصولي الذي يدني الاحتياجات المائية خلال المدة نفسها. قدر النموذج الاول بواقع خطتين مقترحة، تضمنت الخطة الاولى المقترحة عدم فرض القيود التشريعية المتعلقة بتخصيص مساحات معينة للمحاصيل الزراعية الاساسية ذات المساس بمتطلبات الامن الغذائي للسكان وكذلك المحاصيل التي منع استيرادها مؤخرا من قبل الحكومة العراقيةً، اما الخطة الثانية المقترحة فقد تضمنت فرض واضافة قيود المساحات التشريعية التي لم تظهر في جدول الحل الامثل للخطة الاولى. اشارت النتائج المقدرة الى ان هناك فائضا من مورد المياه للخطط الاقتصادية المقترحة على وفق النموذجين المقدريين، بلغت كميته نحو 363.361، 9.178 مليون مترمكعب لكل خطة على الترتيب مقارنة باجمالي كمية مياه الري اللازمة للتركيب المحصولي الراهن والتي قدرت على نحو 4.736726 مليار م3 خلال متوسط المدة المذكورة. كما اشارت نتائج تحليل النموذجين المقدريين الى تفضيل نتائج الخطط ذو القيود التشريعية نتيجة للتوسع في زراعة اغلب المحاصيل والخضر الاساسية والمهمة للاستهلاك المحلي مع احتياجات اقل من الموارد المائية المتاحة.

كلمات مفتاحية: المقنن المائي، المحاصيل الزراعية، التخصيص الامثل، هامش ربح وحدة المياه، العراق.

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INTRODUCTION

The economic use of agricultural productive resources, including the water resource, is one of the most important goals of economic development in all countries of the world, especially in light of the limited and scarcity of most of these productive elements, which necessitates the need for efficient and optimal use of those resources, as water resources in the world are subjected to great continuous pressures as a result of large and rapid increase in the use of water in light of limited and sometimes non-renewable resources, and the emergence of new lifestyle and industrial patterns, led to a significant escalation in the consumption of these resources, causing an imbalance between the available water resources and the actual increasing demand for them (18). The optimal use of water resources in Iraqi agriculture is one of the main economic issues of interest to decision-makers and those responsible for setting agricultural water policies in Iraq, where the use of water resources is one of the important issues facing Iraqi society in light of the current situation (20), due to the stability and scarcity of these resources resulting from the decline in the levels of the Tigris and Euphrates rivers in recent years on the one hand, and the increased needs required of them on the other hand, especially with the continuous population growth and the requirements of economic and social development plans and programs in the field of agriculture and horizontal expansion, in order to establish many agricultural projects that require the provision of water it is necessary for them (2). Therefore and due to the increasing gap between the available and required water resources over time, it has become necessary to study the management and use of those resources in a way that maximizes the return and decreases the necessary needs of them. Iraq depend on the Tigris and Euphrates rivers as a main source of water, as most of Iraq's water quantities come from the Tigris and its tributaries, as these quantities arrange the first place with a percentage of 70%, or approximately three quarters of the total water quantities, followed by the Euphrates river quantities at a rate of about 29% (1 & 12). The agricultural sector in Iraq is also one of the most important economic sectors that use water resources, where it consumes about 86% of the total water uses at the local level, followed by environmental uses at about 6% (11). The research problem lies in the extent to which the current cropping combination is in consistent with the proposed cropping combination, which it is possible to minimize water needs and achieve the maximum possible profit margin in light of the set of restrictions, limitations and available resources, therefore the research problem can be formulated in the following questions:

1 What is the structure of the crop combination that minimizes water needs in Iraqi agriculture?

2- Is it possible to achieve a crop combination that minimizes water needs on the one hand, and the same time maximizes the total profit margin of the water unit on the other hand?

The scarcity of water and the increased demand for its uses requires comprehensive planning to give the water resource a priority by laying the foundations for minimizing the water needs of agricultural crops; the greater consumer of the available water resource than the various economic sectors (4), the feasible option to overcome this problem is to re-allocate those resources optimally under the prevailing cropping combination. This research aims to achieve sub-objectives that focus on finding the best alternatives for the optimal allocation of irrigation water use in Iraqi agriculture. These objectives are as follows:

1. To study the reality of water needs for various agricultural crops in Iraq.
2. To determine the optimum crop combination that minimizes the water needs of the current crop combination during the average period (2017-2020).
3. To determine the optimal crop combination that maximizes the profit margin of the water unit for the crop grouping that minimizes the water needs during the average period (2017-2020).

MATERIALS AND METHODS

Theoretical framework: The research is based on the linear programming technique, which is a quantitative analytical method that was used in the natural and engineering sciences before it was used in the social and administrative sciences, and it is one of the confirmed models and not a probabilistic model. Linear programming is one of the branches and types of mathematical programming; where it is a mathematical method for allocating scarce resources to achieve a goal within certain conditions or restrictions expressed by linear equations (19). Linear programming is also known as a scientific mathematical method concerned by dealing with the problem of resources allocation or specific energies to achieve a specific goal, and this goal is expressed by a linear function called the objective function; this function is often a profit function, a cost function, a productive capacity function, and others (3). The term programming means a set of specific and sequential mathematical steps to achieve a specific aim with optimal results by choosing the optimal alternative from among a group of available alternatives, while the term linear means that the relationship among the variables is linked by linear mathematical functions that can be represented by a straight line (8). Accordingly, the linear programming technique is based on a set of assumptions, namely (20):

1- Linearity: Linear programming assumes that there are linear relationships among the variables of the problem to be solved and applied to them. That is, the assumption here is that the variables of the problem are of the first order; That is, with one power, it cannot be raised to more than one, and accordingly, the relationship between the objective function and the constraints is straight or linear.

2- Addition or the possibility of collect: This means that the quantities of raw materials involved in production, and production quantities are subject to addition, and it is required that there should be no intersection among production activities. In other words, the sum of the outcomes of production activities is the sum of the outcomes of each production activity separately within the single plan.

3- Limitation: This assumption means limited resources and activities, as there is no infinite number of alternative activities and available resources.

4- Non-negative activity size: Means that the values of the decision variables must be positive (non-negative), as this constraint is consistent with the logic of the objective function to be maximized or minimized, which is already present; where it is impossible to deal with it in the case of null or negative.

5- Independence: Choosing any activity does not necessarily involve choosing another activity, this indicates to the independence of the productive elements.

6- Knowledge and complete certainty: Linear programming assumes that all variables, their number technical coefficient values, as well as the constraints, are known and defined before solving them.

The formulation of linear programming models includes three basic components, namely (5)

1. Objective function: It means defining the target function, which requires expressing it in a quantitative manner. The function is placed in the form of a mathematical equation to express maximizing the profit margin or output, or minimizing costs. The possibility of expressing the goal in any problem depends on the type and nature of the problem to be solved using this method. The objective function can be expressed mathematically as follows:

$$\text{Max.}\, OR\ Min.\, \text{Z} = \sum_{j=1}^{n} \text{Cj Xj}$$

Where Z represents the total objective function (maximizing or minimizing), Cj represents the unit of return or cost achieved from one dunum of productive activity j, Xj represents the set of agricultural activities included in the plan.

2. Constraints and limitations: Due to the limited economic resources, the amount of each resource is used as a constraint or limiter in linear programming models. The constraints are the various factors that limit the use of any of the alternative activities that can be used to solve the problem, whether they express the available amount of resource or from other physical, economic or social constraints. The constraints are formulated from the data of the linear programming problem and based on the technical production relations. The matrix of resources or constraints can be expressed mathematically as follows:

Subject To:

$$\sum_{j=1}^{n} \text{Aij Xj} \leq OR \geq \text{Ri} \qquad i = 1 \ldots\ldots\ldots m$$

Where Aij represents the matrix of technical coefficients for the set of resources and constraints included in the plan, and it means the requirements or needs of one dunum of the agricultural crop j from the economic resource i, RI represents the available quantities from the set of resources under study.

3. Non-negative constraint: Economic variables such as production levels and area units cannot take negative values, and these variables have no economic significance if they take negative values. Therefore, the non-negative constraint is placed to avoid economic variables taking negative values, so they take positive values or equal to zero:

$$\text{Xj} \geq 0$$

Study data: In order to achieve the objectives of the research, the study depend on secondary data for the average time period (2017-2020) for the following three agricultural seasons:

1- Data of the agricultural season 2017-2018 (winter – summer)

2- Data of the agricultural season 2018-2019 (winter – summer)

3- Data of the agricultural season 2019-2020 (winter – summer)

These agricultural seasons included a group of the dominant vegetables and crops grown at the country level. The basic information and data were the total areas of the study crops during the seasons referred to, the variable costs and the total returns achieved per dunum of each crop, as well as the available quantities of irrigation water at the level of Iraq and the needs of one dunum of various crops from the water unit. These data were obtained from their various local sources, which included the Ministry of Planning, the Ministry of Agriculture and the Ministry of Water Resources, (9 & 10 & 13), in addition to previous published scientific research and studies related to the subject of the research.

Study models: The research is based on the quantitative mathematical method using the linear programming technique in analyzing the data and extracting the required results by using the statistical program Win QSB (6). With the same line of previous studies and references (7 & 18), two basic economic models have been formulated and analyzed according to the linear programming technique, each of them targeting the rational use of limited water resources. These models take the following mathematical forms:

The first model // linear programming model that minimizes the water needs of the prevailing crop combination during the average period (2017-2020), as this model includes the following plans:

The first plan - a linear programming model that minimizes the water needs of the prevailing crop combination during the average period (2017-2020) without including the legislative restrictions, this model consists of:

1- Objective function: The main objective of this model is to minimizes the water needs per dunum of the optimum crop structure, as well as detecting the amount of shortage in the water resource, meaning that it requires choosing a group of agricultural crops that can minimize the water needs, taking into account the limitations of land, water, and the labor force. The first plan of this model includes forty agricultural crops (18 winter crops, 19 summer crops, and 3 perennial crops).

2- A set of restrictions and limitations: it includes:

A - Land resource constraints: It includes four restrictions, the first of which is related to the total arable areas at the level of Iraq with excluding the areas of gardens, palms and areas of the Kurdistan region, which are not included in the model analysis. The second constraint is related to the total area of winter crops, while the third constraint is related to the total area of summer crops. And the last constraint, the fourth, is related to the total area of perennial crops.

B - Water resource constraints: It was assumed that the amount of irrigation water for the crops of the model under study does not exceed the total amount of available irrigation water, as 12 water restrictions were formulated representing the total monthly water needs for the cropping activities included in the model, where the total amount of available water was distributed according to the months of the year or the agricultural season.

C- Labor force restrictions: It was assumed that the number of working days for the agricultural crops under study does not exceed the total number of available working days, as 4 restrictions for agricultural labor were formulated, representing the total quarterly manual labor needs of the agricultural crops included in the model, where the total number of available working days was distributed according to the four seasons of year.

The second plan - a linear programming model that reduces the water needs of the prevailing crop combination during the average period (2017-2020) with including the legislative restrictions. This model consists of the same components of the first plan with the addition of a set of legislative or regulatory restrictions that represent the areas of the group of crops that farmers must cultivation, as well as the areas of crops that were recently banned from being imported by the Iraqi Ministry of Agriculture (in the event that they do not appear in the results of the first plan of the model).

The second model // linear programming model that maximizes the profit margin of the water unit for the crop combination that minimizes water needs during the average period (2017-2020) with obligation the legislative restrictions, where this model consists of:

1- Objective function: The main objective of this model is to maximize the total profit margin per cubic meter of irrigation water for the optimal crop combination that minimizes water needs. The matter requires choosing a group of agricultural crops that can maximize the total profit margin per cubic meter of water and minimize water needs, taking into account land, water and human constraints. The plan of this model includes a group of agricultural crops that will appear in the results of the matrix analysis of the simplex table of the first model, which are the crops that require the least possible amount of water. The profit margin for one cubic meter of irrigation water for each crop was calculated by dividing the profit margin for one dunum (displayed in Table 1) by the quantity of needs per dunum of irrigation water during the season (11 & 13).

2- A set of restrictions and limitations: it includes:

A - Land resource constraints: It includes four restrictions, the first of which is related to the total arable areas at the level of Iraq by excluding the areas of gardens, palms and areas of the Kurdistan region, which are not included in the model analysis. The second constraint is related to the total area of winter crops, while the third constraint is related to the total area of summer crops. And the last constraint, the fourth, is related to the total area of perennial crops.

B - Water resources constraints It was assumed that the amount of irrigation water for the crops of the model under study does not exceed the total amount of available irrigation water, as 12 water restrictions were formulated representing the total monthly water needs for the cropping activities included in the model, where the total amount of available water was distributed according to the months of the year or the agricultural season.

C- Human labor restrictions: It was assumed that the number of working days for the agricultural crops under study does not exceed the total number of available working days, as 4 restrictions for agricultural labor were formulated, representing the total quarterly manual labor needs of the agricultural crops included in the model, where the total number of available working days was distributed according to the four seasons of year.

D - A set of legislative or regulatory restrictions.

RESULTS AND DISCUSSION

First // the total water needs of the current cropped area in Iraq during the average period (2017-2020): The degree of exploitation of the agricultural area in various rotated agricultural activities leads to an increase in the cropped area of those agricultural activities; therefore the degree of exploitation of the unit area will inevitably affect the needs of the unit of the cultivated area from water resources. The data presented in Table 1 indicate that the total rates of areas planted with various field and vegetable crops at the level of Iraq during the average period (2017-2020) amounted to about 7.554 million dunums, and the water needs for this plan were estimated at about 4.737 billion m3 out of a total of 35.793 billion m3 available for agricultural use during the same mentioned period. Table 1 also shows that the prevailing or actual crop structure at the level of Iraq during three agricultural seasons (2017-2020) consists of forty agricultural crops, and this crop structure achieved a total profit margin estimated at 1029.35838 billion Iraqi dinars with a total profit margin rate per cubic meter of water amounted to about 8751.1 dinars per dunum and about 1.704 billion dinars for the total cultivated areas. The actual crop plan will be used in finding the proposed solutions by the linear programming technique, and the total water needs resulting from it will be compared with the water needs required by the optimal cropping combination that will be produced by the results of the analysis of the linear programming models according to the simplex algorithm.

Second // Results of the analysis of the optimal allocation of water resources in the Iraqi agricultural sector

1- Results of the analysis of the linear programming model that minimizes the water needs of the prevailing crop combination during the average period (2017-2020):

First Plan // Results of the analysis of the linear programming model that minimizes the water needs of the prevailing crop combination during the average period (2017-2020) without including the legislative restrictions:

The results of the analysis of this model (as shown in Table 2) displayed that the total objective function amounted to about 2 billion cubic metres, which means that this plan has achieved the goal of minimizing the water needs necessary for the prevailing crop grouping. And it is noted that four agricultural crops only appear in this plan, which are: Chickpeas (X4), green beans (X23), dry beans (X29) and millet seeds (X40). Where this model suggests an increase and then expansion of the cultivated areas of the mentioned crops, as follows:

- Winter crops group: The model suggests an increase in chickpea crop areas by about 6.355400 million dunums
- Summer crops group: The model suggests increasing the areas of the dry bean crop by about 1,024266 million dunums, and reducing the areas planted with green beans by about 9,616 thousand dunums
- Perennial crops group: The model suggests an expansion of the areas planted with millet by about 153.612 thousand dunums.

By comparing the economic indicators of the actual crop combination during the average period (2017-2020) and the results of the proposed solution for this plan (refer to Table 4), it is note that the profit margin of water unit per dunum for the prevailing cropping combination amounted to about 226 dinars per cubic meter, while the profit margin of water unit per dunum for the proposed combination amounted to about 507 dinars per cubic meter, where the difference between the profit margin of water unit per dunum of the actual and proposed is about 281 Iraqi dinars, with an increase of about 124.3% compared to the current cropping combination.

Table 1. The total water needs and the total profit margin of the water unit according to the cultivated areas at the level of Iraq during the average period (2017-2020)

No.	Crops	Cultivated area / dunums	Annual water ration rate per dunum/m3	Total water needs/million m3	Profit margin of dunum / dinar	Gross profit margin per unit of water / dinar m3	No.	Crops	Cultivated area / dunums	Annual water ration rate per dunum/m3	Total water needs/million m3	Profit margin of dunum / dinar	Gross profit margin per unit of water / dinar m3
1	Wheat	4567000	562.6	2569.3942	127278	226.231781	21	Tomatoes	74239.66667	846.4	62.83645387	41499	49.08908318
2	Barley	1714000	437.2	749.3608	114004	260.7593779	22	Cucumber	61388.6	730.8	44.86278888	71322	97.59441708
3	Pistachios	3377.5	1355	4.5765125	170161	125.5800738	23	Green Beans	9627.5	342.1	3.29356775	71991	210.4384683
4	Chickpeas	389	271.8	0.1057302	150388	553.3038999	24	Eggplant	29017	582.2	16.8936974	71703	123.1587083
5	Lentil	19	271.8	0.0051642	130188	478.9845475	25	Zucchini	8363.266667	609.6	5.09824736	180135	295.4970472
6	Turnip	6971.5	563.3	3.92704595	68462	121.5373691	26	Okra	28523.83333	1456.8	41.5535204	246269	169.0479132
7	Beetle	2097.333	540.15	1.132874582	98239	181.8735536	27	Watermelon	56511.33333	790.4	44.66655784	35512	44.9291498
8	Carrots	1381.333	464.7	0.641905585	62759	135.0527222	28	Melon	37815.33333	790.4	29.88923944	76220	96.43218623
9	Cauliflower	4295	517	2.220515	103580	200.3481625	29	Dry Beans	13132	271.8	3.5692776	71709	263.8300221
10	Cabbage	3430	609.6	2.090928	85564	140.3608924	30	Cotton	79	1309.2	0.1034268	98816	75.4781546
11	Spinach	2111	540.15	1.14025665	129273	239.3279645	31	Sesame	7872.5	662.8	5.217893	172593	260.3998189
12	Lettuce	16802.5	464.7	7.80812175	82626	177.8050355	32	Sun Flower	767	883.2	0.7039104	156441	177.1297554
13	Green Onion	23748.33	784.2	18.62344297	132397	168.8306554	33	Potato	44510.66667	670.4	29.83995094	68682	102.449284
14	Collard Green	2635.5	540.15	1.423565325	73206	135.5290197	34	Dry Onion	22001.16667	784.2	17.2533149	133536	170.283091
15	Radish	3910.5	464.7	1.81720935	80382	172.9761136	35	Yellow Corn	229106	1286.2	294.6761372	11495	8.937179288
16	Beans	1714.333	412.4	0.796650685	383678	825.6466538	36	Sorghum	123637	1041.8	128.8050266	404851	388.6072183
17	Garlic	1777.666	784.2	1.3940462	216914	276.6054578	37	Mung bean	13747.5	815.2	11.206962	117163	143.7230128
18	Peas	128	342.1	0.0437888	229808	671.7567963	38	Hay	113924.6667	1900	216.4568667	54989	28.94157895
19	Rice	266534	1400.8	373.3608272	546695	390.2734152	39	Clover	39687.66667	662.8	26.30498547	71844	108.3946892
20	Pepper	10536.66	904.4	9.529361336	180242	199.2945599	40	Millet Seeds	7290	562.6	4.101354	143252	254.6249556
	Total	7554101	-	4736.726125	-	8751.063			7554101	-	4736.726125	-	8751.063

Total profit margin for the total cultivated areas at the level of Iraq (Iraqi dinars) = SUM (the area planted with the crop x dunum profit margin for the crop) = 1029358380000

Summation profit margin of the water unit for the total cultivated areas at the level of Iraq (Iraqi dinar) = SUM (the area planted with the crop x the profit margin of the dunum water unit for the crop) = 1704405110.16

Source: Organized by the researchers based on the data obtained from the ministries of agriculture, planning and water resources, and according to the following equations:

The total water needs of the crop = the rationed water rate of the crop per dunum X the total area planted with the crop

The total profit margin of the water unit for the crop = the total profit margin of the dunum ÷ the water rationing rate of the crop per dunum

The total profit margin of the dunum for the crop = the total revenue of the dunum - the total cost of the supplies of the dunum

The working hours required for the actual combination amounted to about 234.172 million hours, while it was estimated at about 876 million man-hours for the proposed combination, with an increase of about 274% compared to the current cropping combination.The results of this plan also displayed that there is a surplus in the quantities of water available for use, estimated at 33.683 billion cubic meters, which can be used in agricultural fields or other sectors, in contrast, the results showed that there is a shortage in the resource of the labor force, where the total shortage in hours of human work is about 872.522 million hours, divided into three seasons: the first seasons, the second seasons, and the fourth seasons, which makes it difficult to fill or compensate this shortage in light of the scarcity of this productive element. Although the plan of this model has achieved the goal of minimizing the water needs necessary for the proposed cropping combination by a difference of about 2.636 billion cubic meters, with a decrease of about 56% compared to the water needs necessary for the actual crop combination, but it is noted that the plan of this model suggests an expansion in the cultivated areas of field and fodder crops in excess of the actual demand for them at the country level, in addition to the risk conditions that accompany the cultivation of large areas of these rapidly perishable crops. It is also clear from the results the absence of major agricultural crops that affect the food security of the population, such as wheat, barley, rice, and yellow corn, as well as the absence of most of the vegetable crops that were recently banned from being imported by the Iraqi government, such as tomatoes, cucumbers, eggplant, cabbage, cauliflower, carrots, potatoes, lettuce, garlic, zucchini, peppers, turnip, beetle and green onions. Therefore, this plan is illogical and cannot be applied on the ground due to the absence of all the main crops and important crops for the local consumption. Of course, the results of this plan give a clear indication of the agricultural crop that needs the least amount of water, and this is not always the possible crop under the technical, economic and legislative restrictions and limitations associated with the optimal economic use of the available resources. **Second Plan // Results of the analysis of the linear programming model that minimizes the water needs of the prevailing crop combination during the average period (2017-2020) with including the legislative restrictions:** As an attempt to improve the results of solving the first plan, a set of legislative or regulatory restrictions for the components of the previous plan was included and added. These restrictions relate to the allocation of certain agricultural areas for some field and vegetable crops that did not appear in the results of the first plan, as follows:

1- Wheat area (X1) = 4567000 dunums
2- Barley area (X2) = 1714000 dunums
3- Yellow corn area (X35) = 229106 dunums
4- Tomatoes area (X21) = 74240 dunums
5- Cucumber area (X22) = 61389 dunums
6- Cabbage area (10) = 3430 dunums
7- Cauliflower area (9) = 4295 dunums
8- Potato area (X33) = 44511 dunams
9- Carrots area (X8) = 1382 dunams
10- Lettuce area (X12) = 16,803 dunums
11- Garlic area (X17) = 1778 dunums
12- Zucchini area (X25) = 8364 dunums
13- Pepper area (X20) = 10537 dunums
14- Beetle area (X7) = 2098 dunums
15- Eggplant area (X24) = 29017 dunums
16- Rice area (X19) = 266,534 dunums
17- Turnip area (X6) = 6971.5 dunums
18- Green onions area (X13) = 23748 dunums

Table 3 shows the results of the analysis of the constrained linear programming model with the aim of minimizing the water needs of the current cropping combination and in light of the areas proposed in the plan. It is noted that the cultivation of basic crops and vegetables has been expanded, which led to an increase in the amount of water needs necessary for the new combination, where the total objective function was about 4.373 billion cubic meters, with twenty-one agricultural crops that are:

Table 2. The results of the analysis of linear programming model that minimizes the water needs of the prevailing crop combination during the average period (2017-2020) without including the legislative restrictions

No.	Decision Variable	Solution Value	UnitWater c(j)	Total Contribution	Constraint	Left Hand Side	Right Hand Side	Slack or Surplus
X1	Wheat	0	562.6000	0	Total area	7554101.00	7,554,101.0000	0
X2	Barley	0	437.2000	0	Winter area	6355789.00	6,355,789.0000	0
X3	Pistachios	0	1,355.0000	0	Summer area	1037410.00	1,037,410.0000	0
X4	Chickpeas	6,355,789	271.8000	1,727,503,000	Perennial area	160902.00	160,902.3000	0
X5	Lentil	0	271.8000	0	Water Jan.	46994140.00	2,502,835,000.0000	-2455840860.00
X6	Turnip	0	563.3000	0	Water Feb.	46994140.00	2,630,189,000.0000	-2583194860.00
X7	Beetle	0	540.1500	0	Water Mar.	630373000.00	2,598,584,000.0000	-1968211000.00
X8	Carrots	0	464.7000	0	Water Apr.	630373000.00	2,428,877,000.0000	-1798504000.00
X9	Cauliflower	0	517.0000	0	Water May	583378800.00	2,911,956,000.0000	-2328577200.00
X10	Cabbage	0	609.6000	0	Water Jun.	7543622.00	2,987,539,000.0000	-2979995378.00
X11	Spinach	0	540.1500	0	Water Jul	7544292.00	2,813,391,000.0000	-2805846708.00
X12	Lettuce	0	464.7000	0	Water Aug.	7544292.00	3,289,248,000.0000	-3281703708.00
X13	Green Onion	0	784.2000	0	Water Sep.	7544292.00	3,622,268,000.0000	-3614723708.00
X14	Collard Green	0	540.1500	0	Water Oct.	46994140.00	3,530,667,000.0000	-3483672860.00
X15	Radish	0	464.7000	0	Water Nov.	46994140.00	3,270,067,000.0000	-3223072860.00
X16	Beans	0	464.7000	0	Water Dec.	46994140.00	3,207,116,000.0000	-3160121860.00
X17	Garlic	0	784.2000	0	Labor 1	437923000.00	1,334,604.0000	436588396.00
X18	Peas	0	342.1000	0	Labor 2	319661700.00	1,317,218.0000	318344482.00
X19	Rice	0	1,400.8000	0	Labor 3	1302.90	1,302,901.0000	-1301598.10
X20	Pepper	0	904.4000	0	Labor 4	118892200.00	1,302,901.0000	117589299.00
X21	Tomatoes	0	846.4000	0				
X22	Cucumber	0	730.8000	0				
X23	Green Beans	11.73785	342.1000	4,016				
X24	Eggplant	0	582.2000	0				
X25	Zucchini	0	609.6000	0				
X26	Okra	0	1,456.8000	0				
X27	Watermelon	0	790.4000	0				
X28	Melon	0	790.4000	0				
X29	Dry Beans	1,037,398	271.8000	281,964,800				
X30	Cotton	0	1,309.2000	0				
X31	Sesame	0	662.8000	0				
X32	Sun Flower	0	883.2000	0				
X33	Potato	0	670.4000	0				
X34	Dry Onion	0	784.2000	0				
X35	Yellow Corn	0	1,286.2000	0				
X36	Sorghum	0	1,041.8000	0				
X37	Mung bean	0	815.2000	0				
X38	Hay	0	1,900.0000	0				
X39	Clover	0	662.8000	0				
X40	Millet Seeds	160,902	562.6000	90,523,460				

Objective Function (Min.) = 2,099,995,707

Source: Organized by the researchers based on the results obtained using the statistical program WIN QSB

-Winter crops group: It includes wheat (X1), barley (X2), chickpeas (X4), turnip (X6), beetle (X7), carrots (X8), cauliflower (X9), cabbage (X10), lettuce (X12), green onions (X13) and garlic (X17). Where the total areas exploited with winter crops amounted to about 6,355,789 dunums, and the total annual water needs were estimated at about 3,360476645 m3.

- Summer crops group: It includes rice (X19), peppers (X20), tomatoes (X21), cucumbers (X22), eggplants (X24), zucchini (X25), dry beans (X29), potatoes (X33) and maize (X35). Where the total areas exploited with summer crops amounted to about 1037410 dunums, with annual water needs estimated at about 922364953 m3

- Perennial crops group: includes the millet crop (X40) only, with a total area estimated at about 160902.3 dunums

By comparing the results of the economic indicators (reference to Table 4) between the actual crop combination during the average period (2017-2020) and the proposed combination according to the solution of the second plan, it is noted that the total profit margin of the water unit for the current combination amounted to about 1.704 billion Iraqi dinars, while the total profit margin of the water unit for the proposed the proposed combination amounted to about 1.750 billion Iraqi dinars, where the difference between the profit margin of the water unit of the current and proposed combination is about 46 million Iraqi dinars, an increase of about 3% compared to the current cropping combination. The total amount of irrigation water needed for the proposed cropping combination amounted to about 4.373 billion m^3, while the total amount of irrigation water needed for the current cropping combination was about 4.736 billion m^3, where the difference between the actual and proposed amount of irrigation water amounted to about 363.361 million m^3, a decrease of about 8% compared to the current crop combination. As for the volume of labor used in the current cropping combination, it was estimated at 234.171 million working hours, while the total volume of labor used in the proposed combination was estimated at 202.358 million working hours, which means that the volume of labor used for the proposed cropping combination has achieved a decrease of about 14% compared to its counterpart used for the current cropping combination during the average period (2017-2020). Although this estimated model suggests an increase in the areas of chickpea crops by 3572%, dry sorghum by 2289%, and millet by 2107%, compared to their counterpart actually cultivated during the average period (2017-2020), which means expansion by more than the necessary need for these crops, however, the results of this plan are logical from an economic viewpoint, due to the increase in the profit margin rate for a unit of water per dunum to about 232 dinars per cubic meter of water, and the reduction of water needs in the proposed cropping combination to about 4.373 billion m^3, in addition to the existence of most of the basic crops and vegetables for consumption.

Table 3. The results of the analysis of linear programming model that minimizes the water needs of the prevailing crop combination during the average period (2017-2020) with including the legislative restrictions

No.	Decision Variable	Solution Value	UnitWater c(j)	Total Contribution	Constraint	Left Hand Side	Right Hand Side	Slack or Surplus
X1	Wheat	4,567,000	562.6000	2569394000.00	Total area	7554101.00	7,554,101.0000	0
X2	Barley	1,714,000	437.2000	749360800.00	Winter area	6355789.00	6,355,789.0000	0
X3	Pistachios	0	1,355.0000	0	Summer area	1037410.00	1,037,410.0000	0
X4	Chickpeas	14,285.390	271.8000	3882769.00	Perennial area	160902.3000	160,902.3000	0
X5	Lentil	0	271.8000	0	Water Jan.	572295100.00	2,502,835,000.0000	-1930539900.00
X6	Turnip	6,971.500	563.3000	3927046.00	Water Feb.	574623000.00	2,630,189,000.0000	-2055566000.00
X7	Beetle	2,097.333	540.1500	1132874.00	Water Mar.	659569700.00	2,598,584,000.0000	-1939014300.00
X8	Carrots	1,381.333	464.7000	641905.50	Water Apr.	659569700.00	2,428,877,000.0000	-1769307300.00
X9	Cauliflower	4,295	517.0000	2220515.00	Water May	170298800.00	2,911,956,000.0000	-2741657200.00
X10	Cabbage	3,430	609.6000	2090928.00	Water Jun.	165306900.00	2,987,539,000.0000	-2822232100.00
X11	Spinach	0	540.1500	0	Water Jul	117055700.00	2,813,391,000.0000	-2696335300.00
X12	Lettuce	16,802.500	464.7000	7808122.00	Water Aug.	169309400.00	3,289,248,000.0000	-3119938600.00
X13	Green Onion	23,748.330	784.2000	18623440.00	Water Sep.	78471410.00	3,622,268,000.0000	-3543796590.00
X14	Collard Green	0	540.1500	0	Water Oct.	23301990.00	3,530,667,000.0000	-3507365010.00
X15	Radish	0	464.7000	0	Water Nov.	587200100.00	3,270,067,000.0000	-2682866900.00
X16	Beans	0	464.7000	0	Water Dec.	576184600.00	3,207,116,000.0000	-2630931400.00
X17	Garlic	1,777.666	784.2000	1394046.00	Labor 1	49026350.00	1,334,604.0000	47691746.00
X18	Peas	0	342.1000	0	Labor 2	45511120.00	1,317,218.0000	44193902.00
X19	Rice	266,534	1,400.8000	373360900.00	Labor 3	29767720.00	1,302,901.0000	28464819.00
X20	Pepper	10,536.670	904.4000	9529361.00	Labor 4	78052930.00	1,302,901.0000	76750029.00
X21	Tomatoes	74,239.660	846.4000	62836450.00				
X22	Cucumber	61,388.600	730.8000	44862790.00				
X23	Green Beans	0	342.1000	0				
X24	Eggplant	29,017	582.2000	16893700.00				
X25	Zucchini	8,363.266	609.6000	5098247.00				
X26	Okra	0	1,456.8000	0				
X27	Watermelon	0	790.4000	0				
X28	Melon	0	790.4000	0				
X29	Dry Beans	313,714.100	271.8000	85267490.00		Objective Function (Min.) = 4,373,364,894		
X30	Cotton	0	1,309.2000	0				
X31	Sesame	0	662.8000	0				
X32	Sun Flower	0	883.2000	0				
X33	Potato	44,510.666	670.4000	29839950.00				
X34	Dry Onion	0	784.2000	0				
X35	Yellow Corn	229,106	1,286.2000	294676100.00				
X36	Sorghum	0	1,041.8000	0				
X37	Mung bean	0	815.2000	0				
X38	Hay	0	1,900.0000	0				
X39	Clover	0	662.8000	0				
X40	Millet Seeds	160,902	562.6000	90523460.00				

Source: Organized by the researchers based on the results obtained using the statistical program WIN QSB

Table 4. Comparison between the results of the current plan and the first linear programming model without and with the imposition of legislative restrictions for the cropping combination in the case of minimizing water needs during the average period (2017-2020)

Economic Indicators	Prevalent or actual crop combination plan	Results of the proposed crop combination without legislative restrictions	Results of the proposed crop combination with legislative restrictions
Suggested number of crops	40	4	21
Total cultivated area / million dunums	7.554101	7.554101	7.554101
Total profit margin of water unit / billion Iraqi dinars	1.70440511016	3.83135171261	1.75043834345
Profit margin of water unit per dunum/ m^3	226	507	232
Average annual water requirement/billion m^3	4.736726	2.099995707	4.373364894
Average annual work requirement/million hours	234.17158	876.478125	202.358112

Source: Organized and calculated by the researchers based on the results of analyzing the study data

2- Results of the analysis of the linear programming model that maximizes the profit margin of the water unit for the crop combination that minimizes water needs during the average period (2017-2020): This model aims to develop an alternative plan for the crop combination that minimizes water needs with the imposition of legislative restrictions and to achieve the maximize profit margin of the cubic meter of the water resource (the profit margin of the dunum ÷ the amount of irrigation water needed per dunum). In this model, the coefficients of the objective function represented by the water needs of various crops were replaced by the rates of profit margin of water unit per dunum for the group of crops and vegetables only that appeared in the tables of the optimal solution for the first model, which were twenty-two agricultural crops, namely: wheat, barley, chickpeas, turnip, beetle, carrots, cauliflower, cabbage, lettuce, green onions, garlic, rice, peppers, tomatoes, cucumbers, green beans, eggplants, zucchini, dry beans, potatoes, yellow corn and millet.After analyzing the data related to this model, the estimated results indicated that only three agricultural crops appeared in the optimal solution table: chickpeas, rice and millet, with proposed areas amounting to about 6.355 million, 1.037 million, and 161 thousand dunums of each, respectively, achieving a total profit margin of the water unit of about 3.963 billion Iraqi dinars, which is higher than the total profit margin of the water unit of the current crop combination, with a difference of about 2.259 billion Iraqi dinars, an increase of about 132.5% compared to the actual crop combination. Despite the economic value of this model plan, it is also illogical and cannot be recommended due to the absence of most strategic agricultural crops and important crops needed for local consumption. Of course, the results of solving this model give clear indications of the crop with the highest profit margin per unit of water, and this does not necessarily have to be the continuation of that crop is the possible activity in light of the technical and economic constraints and limitations that accompany the optimal exploitation of the available resources. As an attempt to improve the results of solving this model, the model was restricted by adding the areas of crops and vegetables that did not appear in the previous plan, namely: wheat, barley, turnip, beetle, carrots, cauliflower, cabbage, lettuce, green onions, garlic, peppers, tomatoes, cucumbers, green beans, eggplant, zucchini, dry beans, potatoes and yellow corn, in addition to a set of basic constraints imposed on the model. Table 5 shows the results of the analysis of the new model after restricting it to the mentioned crops, as the total target function amounted to about 1.790 billion Iraqi dinars, with twenty agricultural crops:

- Winter crops group: includes wheat, barley, chickpeas, turnip, beetle, carrots, cauliflower, cabbage, lettuce, green onions and garlic
- Summer crops group: includes rice, peppers, tomatoes, cucumbers, eggplant zucchini, potatoes and yellow corn, with the exclusion of green beans and dry beans from the plan
- Perennial or fodder crops group: it includes millet only

By comparing the results of the economic indicators (referring to Table 6) between the actual crop combination during the average period (2017-2020) and the proposed combination according to the solution of the second model, it is noted that the total profit margin of the water unit for the current combination amounted to about 1.704 billion Iraqi dinars, while the total profit margin of the water unit for the proposed combination amounted to about 1.790 billion Iraqi dinars, a difference of about 86 million Iraqi dinars, an increase of about 5% compared to the current cropping combination. The total amount of irrigation water needed for the proposed cropping combination amounted to about 4.727 billion m3, while the total amount of irrigation water needed for the current cropping combination amounted to about 4.736 billion m^3, with a difference of about 9 million m^3, a decrease of about 0.2% compared to the current cropping combination. As for the volume of labor used in the current cropping combination, it was estimated at 234.171 million working hours, while the total volume of labor used in the proposed combination was estimated at 180,711 million working hours, which means that the volume of labor used for the proposed cropping combination has achieved a decrease of about 23% for its counterpart used in the current cropping combination. Although the plan of this model suggests to increase the areas of chickpea crops by 3573%, rice by 118% and millet by 2107%, compared to their counterpart actually cultivated during the average period (2017-2020), which means expanding more than the necessary need for these crops, but the results of this plan are logical from an economic viewpoint as well, due to the high rate of profit margin of water unit per dunum to about 237 dinars m^3 of water and the decrease of water needs in the proposed cropping combination to about 4.728 billion m3, in addition to the existence of most the basic crops and vegetables for consumption.

Table 5. Results of the analysis of the linear programming model that maximizes the profit margin of the water unit for the crop combination that minimizes water needs during the average period (2017-2020) with the imposition of legislative restrictions

No.	Decision Variable	Solution Value	Unit Profit c(j)	Total Contribution	Constraint	Left Hand Side	Right Hand Side	Slack or Surplus
X1	Wheat	4567000.00	226.2318	1033200630.60	Total area	7,554,101.0000	7,554,101.0000	0
X2	Barley	1714000.00	260.7594	446941611.60	Winter area	6,355,789.0000	6,355,789.0000	0
X4	Chickpeas	14287.10	553.3039	7905108.15	Summer area	1,037,410.0000	1,037,410.0000	0
X6	Turnip	6971.50	121.5374	847297.98	Perennial area	160,902.3000	160,902.3000	0
X7	Beetle	2097.30	181.8736	381443.50	Water Jan.	558083800.00	2,502,835,000.0000	-1944751200.00
X8	Carrots	1381.30	135.0527	186548.29	Water Feb.	560411800.00	2,630,189,000.0000	-2069777200.00
X9	Cauliflower	4294.00	200.3482	860295.17	Water Mar.	645358500.00	2,598,584,000.0000	-1953225500.00
X10	Cabbage	3430.00	140.3609	481437.89	Water Apr.	645358500.00	2,428,877,000.0000	-1783518500.00
X12	Lettuce	16802.50	177.8050	2987568.51	Water May	280161900.00	2,911,956,000.0000	-2631794100.00
X13	Green Onion	23748.30	168.8307	4009442.11	Water Jun.	275169800.00	2,987,539,000.0000	-2712369200.00
X17	Garlic	1777.00	276.6055	491527.97	Water Jul	226918500.00	2,813,391,000.0000	-2586472500.00
X19	Rice	580248.80	390.2734	226455672.02	Water Aug.	279172200.00	3,289,248,000.0000	-3010075800.00
X20	Pepper	10536.00	199.2946	2099767.91	Water Sep.	78471190.00	3,622,268,000.0000	-3543796810.00
X21	Tomatoes	74239.70	49.0300	3639972.49	Water Oct.	9090595.00	3,530,667,000.0000	-3521576405.00
X22	Cucumber	61388.60	97.5944	5991183.58	Water Nov.	572988800.00	3,270,067,000.0000	-2697078200.00
X23	Green Beans	0	210.4385	0	Water Dec.	561973400.00	3,207,116,000.0000	-2645142600.00
X24	Eggplant	29017.00	123.1587	3573696.00	Labor 1	45261780.00	1,334,604.0000	43927176.00
X25	Zucchini	8363.20	295.4970	2471300.51	Labor 2	37982010.00	1,317,218.0000	36664792.00
X29	Dry Beans	0	263.8300	0	Labor 3	29767630.00	1,302,901.0000	28464729.00
X33	Potato	44510.70	102.4493	4560090.06	Labor 4	67700260.00	1,302,901.0000	66397359.00
X35	Yellow Corn	229106.00	8.9372	2047566.14	Objective Function (Min.) = 1,790,102,000			
X40	Millet Seeds	160902.00	254.6250	40969671.75				

Source: Organized by the researchers based on the results obtained using the statistical program WIN QSB

Table 6. Comparison between the results of the current plan and the second linear programming that maximizes the profit margin of the water unit for the crop combination that minimizes water needs during the average period (2017-2020)

Economic Indicators	Prevalent or actual crop combination plan	Results of the proposed crop combination without legislative restrictions	Results of the proposed crop combination with legislative restrictions
Suggested number of crops	40	3	20
Total cultivated area / million dunums	7.554101	7554101	7554101
Total profit margin of water unit / billion Iraqi dinars	1.70440511016	3.963000	1.790102000
Profit margin of water unit per dunum/ dinar m^3	226	525	237
Average annual water requirement/billion m^3	4.736726	3.271231	4.727548
Average annual work requirement/million hours	234.17158	804.894204	180.711691

Source: Organized and calculated by the researchers based on the results of analyzing the study data

CONCLUSIONS

Through the findings of the research, it can be concluded that the best logical plans for the results of solving the proposed linear programming models, which can be used by economic decision-makers in the country in the future in a case of optimal use of water as an alternative to the actual current plan, are the results of plans with legislative restrictions as a result of the expansion in the cultivation of most basic and important crops and vegetables for local consumption. Based on these findings, the study recommends the necessity of re-maintenance of the irrigation networks in Iraq in order to be able to operate with high efficiency and reduce the wastage of irrigation water that irrigates the various fields and farms at the country level.

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