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ARTICLE

Development of Modeling Forage Crop Irrigation Using Fao– Aqua Crop 2012 Program, Salamiyya, Syria

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ABSTRACT

To promote forage crop productivity in the drought–suffering Salamiyya area, overpopulation, and water mismanagement in the agricultural field, the modified FAO– Aqua Crop 2012 program which can be used with other programs to simulate the recommended strategies to select the best one for cultivating alfalfa, barley, and vetch, compared with the area's farmer practices (control). The results showed the importance of the application of mathematical modeling to cope with the climate of the area, cultivation date, and land suitability for each crop from the method of irrigation scheduling. The results of the statistical analysis proved that there are significant differences between the number of days even the date of cutting, Branches number per plant, Plant's height, and yield at (5%) level. Furthermore, the agricultural water productivity would be increased by 63%, 45%, and more than 120% compared to the traditional field application for barley, vetch, and alfalfa, respectively. The program confirmed that the sprinkler irrigation method is the best in terms of (WUE) and suitability to environmental and economic conditions. Employing the virtual water concept and changing the alfalfa cultivated area to barley or vetch, we can get a profit of 898,42 $/ha, saving 0.4–0.6 MCM/30–45 ha per year. Consequently, going ahead of the context of achieving sustainable development in this area. Finally, the integrated program AquaCrop

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and other programs can be considered modern and sophisticated tools to save water and costs in addition to obtaining very accurate results.

Keywords: Forage Crop; AquaCrop 2012; Strategies; Agricultural Water Productivity; Virtual Water

1. Introduction

Water is the basis of human life on Earth, and its importance increases in regions characterized by limited water resources, such as the Mediterranean countries. An example of this is Syria, which is characterized by irregular rainfall, most of which is lost through evaporation, surface runoff, and only a small amount of it reaches the seas. With the continuation of climate change, population growth, economic development, and agricultural expansion aimed at increasing production to meet the continuous demand for food commodities, there is a clear decrease in fresh water resources, which creates a state of water deficit in meeting the needs of various sectors, and thus the emergence of a clear crisis that may worsen in the near future [1], as the availability of renewable water resources and their uses are determined according to their quantitative and qualitative distribution [2]. This requires great efforts to monitor and evaluate hydrological variables under various environmental and climatic conditions [3]. In light of the increasing population and competition for available water, in addition to the many other uses, irrigated agriculture must produce more food with less water to achieve food security [4, 5]. Any serious vision aimed at expanding irrigated areas and increasing the economic return of various crops cannot be isolated from developing the technical and economic efficiency of water use in agriculture and rationalizing it, as various efforts have been made in this field, most of which were ineffective [6]. Addressing the difficult problems facing irrigation management requires a better understanding of the water balance within the irrigation project through the reuse of non–traditional treated water, familiarity with climatic data, soil characteristics, crop selection, and applied irrigation efficiency. The complexity of irrigation projects at the water basin level requires advanced mathematical models such as the Aqua Crop program [7], through which water is reallocated according to priorities that start from the farm to the irrigation project and then the entire basin [8]. To mitigate groundwater depletion, the Syrian Ministry of Agriculture and Agrarian Reform granted loans farmers to implement advanced irrigation techniques through the Modern Irrigation Transformation Project, which was implemented in most Syrian governorates, for example, Hama Governorate and particularly, Salamiyya, where the percentage of lands irrigated by modern irrigation methods in 2010 amounted to about 42% of the total irrigated area of about 835,170 ha, while there is no modern irrigation technology in the Salamiyya Research Center (the study area) despite the presence of the water source, as it is famous for its animal production and improvement of Awassi sheep. As a result of the recommendations of the Ministry of Agriculture to support the animal sector with the appropriate animal feed, the center planted various fodder crop such as alfalfa, barley, vetch, and others, but without knowing about the depletion of the water resource, as it cultivated them like the farmers do. Hence, there was an urgent need to improve water management and application, especially after the drying up of many wells in the center and the Salamiyya region as a whole during the past two decades, which led to a decline in alfalfa cultivation, while rainfed barley cultivation continued with a weak productivity as well without following any means to increase it. It relied on importing the necessary fodder instead of following the correct methods for growing crop. Representing the climate of the studied region (hydro climatic balance) after correcting errors, filling gaps, determining the optimal investment dates for rainwater, and how to increase the productivity of agricultural crops are an urgent necessity to achieve sustainable development in it. Whereas, it suffers from drought, the spread of desertification, and the tendency of its farmers to rely on animal production more than plant production, not to mention the migration of many of its people to work abroad and leave their lands. Due to the expansion of the genetic improvement program for Awassi sheep at Salamiyya farm (Agricultural Scientific Research Center), there is an urgent need to increase the productivity of forage crop such as alfalfa, barley and vetch, as they contain complete nutrition for the animal, whether in the form of green fodder or dry fodder, especially during breeding and improvement programs. Since the region falls under the arid and semi–arid regions, and suffers from water scarcity at the present time, it was necessary to study and estimate the water requirement for this type of forage crop accurately despite the lack of measurement tools, and to develop a model for each of them that makes their cultivation a real and simple matter and removes doubts about preferring other crops over them, especially at the present time when prices are high and service costs are increasing. This research aims at getting the best solutions and strategies to improve the integrated management of the farm, both animal and plant at Salamiyya. That is by improving the productivity of agricultural water for the forage crop grown therein, by following mathematical modeling and simulating the actual reality using the modified Aqua Crop program and its supporting programs on alfalfa, barley, and vetch.

2. Materials and Methods

This research consists of two parts: The first: A study simulating the actual agricultural reality at Salamiyya generally, and estimating the climate gap and the appropriate time to cultivate each crop using the ArcGIS and NewLoc–Clim1.10 programs and representing that on the forage crop alfalfa, barley and vetch particularly. The second part: It is represented by implementing scientific experiments for these crops in the Salamiyya Research Center, and adding the means and strategies capable of improving their water productivity using the AquaCrop program and setting the best timetable for them.

Data were collected to draw a map of the Salamiyya region in general and the study site particularly using the ArcGIS program, as shown in **Figure 1**. The study was conducted at Salamiyya Agricultural Scientific Research Center in the village of Al–Karim (the fourth stability area), located 25 km east of the governorate of Hama, and 6 km west Salamiyya city at a longitude of 36.00° E and a latitude of 34.20° N and an altitude of 435 m above sea level.

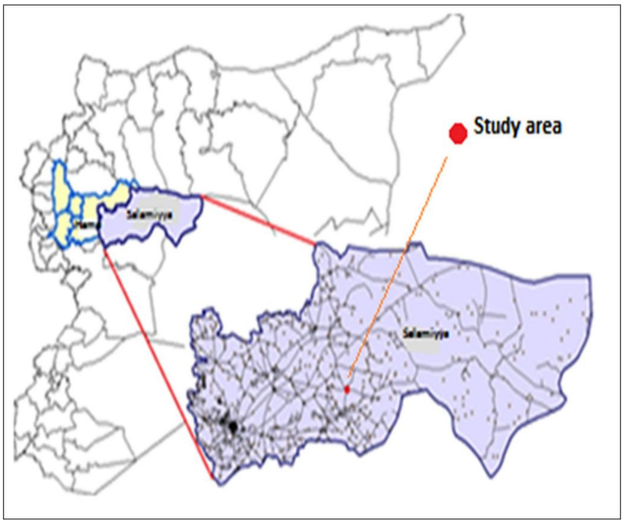

Figure 1. The derived map of Salamiyya area and the site of study area by ArcGIS.

Data on the studied forage crop and their productivity during the past decade and the irrigation method applied to them were also collected, as given in **Table 1**.

Table 1. The yield of the studied crop (t/ha) at Salamiyya region.

Date	Alfalfa (Green Fodder)	Non– Irrigated Vetch	Non– Irrigated Vetch– Barley	Non– Irrigated Barley
2007	13.9	0.72	2.5	0.38
2008	14.4	3.5	1.5	0.17
2009	12.7	0.92	1.9	0.82
2010	17.8	3.2	1.2	0.95
2011	18.2	2.4	2.0	0.42
2012	13.4	2.4	2.4	1.19
2013	13.7	2.5	1.5	0.81
2014	12.3	3.1	1.1	0.38
2015	12.2	3.1	2.1	1.21
2016	11.4	3.6	1.6	0.50
2017	11.8	3.5	2.5	0.50

Data on rainfall, temperatures, relative humidity, wind and solar radiation were collected and analyzed. Furthermore, these data were included daily and monthly in the program after modification for the period from 1/1/1975 to 31/12/2011. The simulation process was carried out for the entire area and the climatic data were determined during each agricultural season as shown in **Table 2**.

Soils were collected and described in every place in the study area whereas the two soils (Inceptisols and Calcic Xerosols) prevailed according to [9]. Soil analysis during the three successive seasons, where the bulk density ranged between 1.11–1.32 g/cm^3 in the 0–60 cm depth. The volumetric field capacity was between 40.43–41.9% for the depth of 0–45 cm, and 42.9–44.2% at the depth of 60–90 cm (**Table 3**). AquaCrop and SPAW programs were calibrated using the properties presented in **Table 3**.

Table 2. Average climatic data during the field experiment seasons 2014–2017.

Area Monthly Average	Temp (°C) Min	Max	Relative Humidity Min	Max	Solar Radiation (hour)	Evaporation (mm)	Rainfall (mm)
Oct	16.17	32.04	26.83	77.29	9.67	111.47	3.73
Nov	11.23	26.22	30.96	78.34	7.28	70.13	10.90
Dec	7.18	19.18	49.20	87.73	5.61	38.47	45.93
Jan	1.68	11.39	59.51	91.43	4.67	36.40	55.80
Feb	3.19	15.87	43.54	87.26	6.54	50.50	16.77
Mar	6.67	19.40	40.24	86.67	6.88	62.87	34.17
Apr	9.49	25.07	27.92	79.24	8.70	110.83	17.73
May	14.18	29.57	25.24	77.55	10.38	265.90	6.07
Total/Average	8.72	22.34	37.93	83.19	7.47	746.57	191.10

Table 3. The hydrophysical properties for the soil of the experiment.

Depth (cm)	(gr/cm^3) Bulk Density	Particle Density	Porosity (%)	Field Capacity (%) Weighting	Volumetric	Wilting Point (%) Weighting	Volumetric	Aeration (%) At 60%	At 70%	At 80%
0–15	1.11	2.58	56.98	36.42	40.43	19.80	21.98	32.7	28.6	24.6
15–30	1.18	2.66	55.64	35.00	41.30	19.21	22.66	30.6	26.4	22.2
30–45	1.25	2.69	53.53	33.52	41.90	18.38	22.97	28.1	23.9	19.7
45–60	1.32	2.70	51.11	32.20	42.50	18.06	23.84	24.7	20.4	16
60–75	1.34	2.72	50.73	32.02	42.90	18.21	24.40	23.7	19.3	14.8
75–90	1.39	2.72	48.89	31.80	44.20	18.03	25.06	21.2	16.6	11.9

The physical and chemical properties of the soil were studied by analyzing the soil samples hydro–physically, chemically and fertilely in the laboratories of the General Commission for Agricultural Scientific Research (GCSAR), as shown in **Table 4**.

The experimental soil was characterized as deep yellowish structure containing close proportions of sand and silt, with an increased proportion of clay to give a loamy texture. The proportion of silt ranged between 24–41%, while the proportion of sand was low, about 19–28%. The pH of the saturated soil extract tended towards basicity, as it ranged between 7.4–7.6. The electrical conductivity Ec in the saturated extract ranged between 0.65–1.2 dS/m. The proportion of calcium carbonate was average, 21.8–26.8%, with a slight increase in the subsurface layers due to the presence of spots of precipitated calcium carbonate. The soil is also very poor in its organic matter content, as it did not exceed 0.857% in the surface layer at a depth of 0–15 cm. As for total nitrogen and available phosphorus, the soil is poor. As for the exchangeable potassium, the soil is very rich in this element (580.5–709 mg/kg).

Table 4. The chemical properties and mechanical analysis for the soil of the experiment.

Depth (cm)	PH	Ec (dS/m)	(gr/100gr soil) $CaCO_3$	$Ca(OH)_2$	OM	Total N	mg/kg Available Phosphor	Exchange-able –K	Particle Size Distribution (%) Sand	Clay	Silt	Ure
0–15	7.4	0.65	23.99	8.23	0.857	0.0435	7	580.5	28	24	48	Loam
15–30	7.5	0.67	24.75	9.41	0.780	0.0039	7	580.5	28	24	48	Loam
30–45	7.4	1.2	21.75	9.41	0.780	0.0039	4	682	21	33	46	Clay Loam
45–60	7.5	1.2	23.22	9.41	0.571	0.0285	3	725	19	41	40	Silty Clay
60–75	7.6	1.2	25.77	10	0.571	0.0285	2	709	20	34	46	Silty Clay Loam
75–90	7.5	1.15	26.28	9.41	0.19	0.095	2	709	21	33	46	Loam

Evapotranspiration was calculated and errors and gaps were corrected using the ET_0Calc program[10]. Calibration was done with the NewLoc–Clim 1.10 program to calculate the maximum evapotranspiration[11].

Most of the data for the AquaCrop 2012 program were entered for each of the studied crop, and the program was run and calibrated[12]. The program allows for setting a timetable for the relationship between yield and actual evapotranspiration, which was ignored by most previous studies. From this, the crop response coefficient to water was deduced according to the Equation (1):

$$Ky\left(1-\frac{ETa}{ETx}\right)=1-\frac{Ya}{Yx} \tag{1}$$

ETa, ETx: Actual and maximum evapotranspiration, respectively (mm).
Ya, Yx: Actual and maximum yield, respectively (kg/ha).

The Implementation of the Experiment:

The three crops, alfalfa, barley and vetch, were planted on 11/10/2014. The experiment for each crop was designed according to a completely randomized block design with three replicates. The experimental land was prepared by cultivating it with a disc plough, two perpendicular ploughs, then a smoothing plough was carried out using a duck–foot plough, called a cultivator. The necessary irrigation was provided as supplementary irrigation when an average of 55% of the available water in the soil was exhausted. Each treatment was given its full requirement and a comparison was made with the practices of the region's farms. Each experiment was treated according to the following scientific strategies: For the alfalfa experiment, the following fertilizer recommendation was applied (N fertilizer 46% at a rate of 100 kg/ha, superphosphate fertilizer at a rate of P_2O_5 at a rate of 90 kg/ha, and 20 kg/ha of seeds) compared to the practice of the farmer as a control (N fertilizer 46% at a rate of 30 kg/ha and 14 kg/ha of seeds). The irrigation, mowing and fertilization processes were followed, and superphosphate was added with planting, while nitrogen was added in the form of urea in about two batches, the first at the beginning of planting and the second one month after planting, and the addition was repeated according to the Tawakul method[13]. The plants were harvested at the beginning of flowering and at a height of 60–90 cm with a hand mower, and the harvests ranged from 5–10 times during one season, and the green yield readings were taken. The experiment lasted for three seasons and ended in 2017. As for the barley crop, it was grown in a crop rotation with vetch and in a conservation agriculture method, providing all the required needs, as the climate of the region is suitable for growing these two crops. Simulation was carried out with the data of a previous experiment to correct errors in the same place[14]. After extracting the results of these strategies, they were formulated using the AquaCrop program and the crop response coefficient to water was estimated correctly within the conditions of the region. The statistical aspects were also studied using the Genstat V12.0 program. Finally, the virtual water for each crop was estimated, which represents the water needed to produce the commodity[15]. The economic feasibility was also calculated based on the descriptive economic analysis method, according to the partial budget used to estimate the profit resulting from small organizational changes on the farm[16].

3. Results and Discussion

The NewLoc–Clim 1.10 program was calibrated and its operation was verified by doing the following:

A– Correcting and calculating the gaps in evapotranspiration, especially in the place where the research was carried out during the past two decades, using the ET0 Calc program.

B– Entering the inferred and corrected data on a daily basis and calculating the climatic water balance for the studied area using the NewLoc–Clim 1.10 program, as in **Figure 2**.

The results showed that the rainfall rate for a 75% probability (dry year) will be about 1.8 mm/day during the period from November 19 to March 5 (the blue growing period, which is the winter months) while it will decrease to 1.7 mm/day during the period from March 6 to March 27 and from November 8 to 18 (the green growing period, which is the spring and autumn months). The water increase is 103 mm during the winter months, when the maximum evapotranspiration equals the actual evapotranspiration, and most of this water increase flows into the soil. The maximum benefit of rainwater for irrigating crop ends during the last two–thirds of March and begins in mid–November, when the rainfall rate is greater than half the maximum evapotranspiration rate. By applying supplementary irrigation to the studied crop according to the crop coefficient for each of them and extracting the maximum evaporation–transpiration values from the above diagram, the actual evaporation–transpiration can be deduced for alfalfa, barley and vetch.

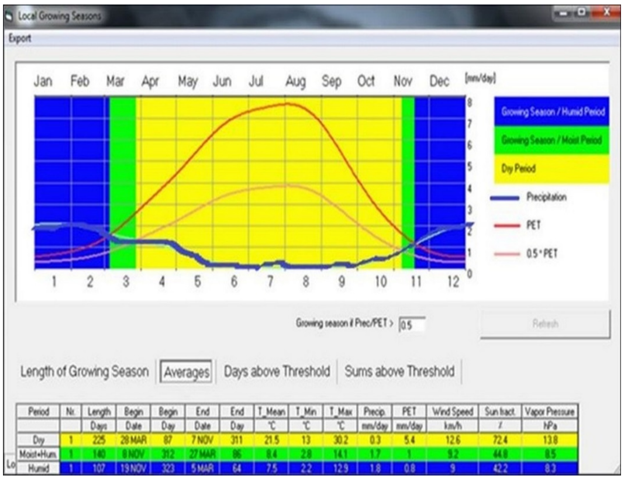

Figure 2. Climate water budget diagram for the probability of a dry year at a probability of 75% for the Salamiyya region using the NewLoc–Clim 1.10 program.

By simulating the depth of water available in the experimental land using the SPWA program, as in **Figure 3**, the irrigation programming for the system of these crops can be estimated (how much, when and how do we irrigate?).

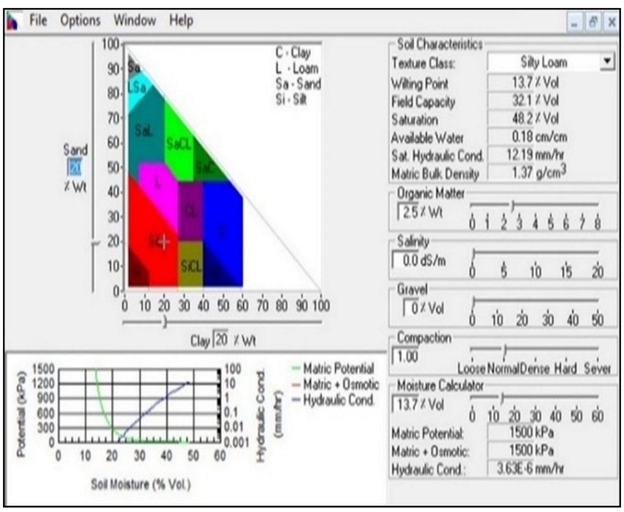

Figure 3. Modeling of hydrophysical soil specifications using SPAW program.

The results of the SPAW program after simulating the actual reality of the soil showed that it is of a silty loamy soil, with a sand content of about 20%, available water to the plant of about 180 mm/m, and the infiltration rate of about 12.2 mm/h. This requires reducing the value of the maximum allowable moisture depletion coefficient (MAD) and increasing the frequency of irrigation in small quantities in accordance with the effective root spread area and the specifications of each planted crop, and its actual need to reach acceptable production under the conditions of the other region. This was agreement with the results of[17] when modeling irrigation in China, where they deduced a mathematical model for each type of soil by simulating lysimeter readings.

3.1. Modeling Irrigation Using Aquacrop 2012 Software

The area ratios of each crop, its properties, the soil texture, the calculated reference evapotranspiration, all other area specifications were entered in the integrated AquaCrop program. By running the program, it gave valuable results tabulated in programming the irrigation of barley and vetch crops as a crop rotation using the conservation agriculture method during the three seasons, respectively. A thing which is other programs cannot work out. The amount of water required to be provided to the barley crop by surface irrigation method was (4870.2 m^3/ha), (4174.4 m^3/ha) by sprinkler irrigation method and (3246.8 m^3/ha) by drip irrigation method, as in **Table 5**. When linking the simulation result of the whole area with the NewLoc–Clim 1.10 program as in **Figure 3**, rainfall can compensate for irrigating germination and tillering phases, so that the amount of water required to be provided in the most appropriate method (sprinkler) is reduced to 2688.5 m^3/ha. By considering the adjusted yield (4.8 t/ha) which is much higher than one of the area's farmer and the center (1.4–2.5 t/ha) as in **Table 1**, the crop response coefficient in this type of soil will record 0.73.

While the amount of water required for the vetch was (3383 m^3/ha) by surface irrigation, (2706.4 m^3/ha) by sprinkler irrigation method and (2253.5 m^3/ha) by drip irrigation method, as in **Table 6**. When linking with the NewLoc–Clim 1.10 program, rainfall can be replaced by two irrigations in the germination and growth phases, and then the amount of water required by the most appropriate method (sprinkling) reduce to 1806.3 m^3/ha. When taking the adjusted yield (7.3 t/ha) into account, which is much higher than one of the farmer and the center (2.4–3.6 t/ha), the crop response coefficient in this type of soil will record 1.08, and these results were in agreement with the results of[18].

Table 5. Results of modeling barley irrigation using AquaCrop program.

Growth Stages	Germination	Seedling Growth, Tillering, Stem Elongation,	Booting, Ear Emergence	Flowering	Milk Development	Dough Development	Ripening	Sum
Date	10/11–12/1	13/1–1/3	2/3–1/4	2/4–12/4	13/4–23/4	24/4–3/5	4/5–13/5	
The Long of the Stage (T), (day)	64	48	31	11	11	10	10	185
Root Depth (RD), (m)	0.3	0.6	0.75	0.9	1.05	1.05	1.05	
Reference Evapo Transpiration (ET0), (mm/day)	1.44	1.43	1.93	2.14	4.72	5.36	5.76	
Crop Coefficient (Kc)	0.76	0.99	1	0.87	0.7	0.7	0.27	
Crop Water Consumptive use (mm) ET = ET0 x Kc	70.04	67.95	59.83	20.48	36.37	37.54	15.54	307.75
Moisture Allowed Depletion (MAD)	0.8	0.788	0.605	0.577	0.581	0.581	0.781	
Total Available Water, TAW (mm) TAW = (q fc – q wp) x RD x (10)	55.2	110.4	138	165.6	193.2	193.2	193.2	1048.8
Net–Available Water, D (mm) = TAW x P	44.16	87.00	83.49	95.55	112.3	112.3		534.7
The Number of Irrigations = Crop water consumptive use/ Net–available water	2	2	1	1	1	1		6
Net–Actual Irrigation (mm) = Crop water consumptive use/modified irrigations number	35.02	33.97	59.83	20.47	36.36	37.54		150.6
Gross Irrigation (mm) = Net–actual irrigation/ Ea (efficiency of added water)	58.36	56.63	99.72	34.13	60.61	62.57		372.0
Crop Growth Stage Water Requirement (Surface irr, mm)	116.74	113.26	99.72	34.13	60.61	62.57		487.02
Crop Growth Stage Water Requirement (Sprinkler irr, mm)	100.06	97.08	85.47	29.26	51.95	53.63		417.44
Crop Growth Stage Water requirement (Drip irr, mm)	77.82	75.50	66.48	22.76	40.41	41.71		324.68

Table 6. Results of modeling vetch irrigation using the AquaCrop program.

Growth Stage	Germination	Development	Flowering	Ripening	Sum
Date	10/11–11/1	12/1–30/3	31/3–13/4	14/4 –11/5	
The long of the stage (T), (day)	63	78	14	28	183
Root depth (RD), (m)	0.4	0.75	1.05	1.17	
Reference evapotranspiration (ET0), (mm/day)	1.41	1.57	1.95	5.25	
Crop coefficient (Kc)	0.76	0.89	0.97	0.77	
Crop water consumptive use (mm) ET = ET0 x Kc	67.51	108.99	26.48	113.19	316.17
Moisture Allowed Depletion (MAD)	0.8	0.788	0.577	0.781	
Total Available Water, TAW (mm) TAW = (q fc – q wp) x RD x (10)	73.6	138	193.2	215.3	620.1
Net–available water, D (mm) = TAW x P	58.88	108.74	116.89		
The number of irrigations = Crop water consumptive use/Net available water	2	11	1		4
Net–actual irrigation (mm) = Crop water consumptive use/modified irrigations number	33.76	108.99	26.48		169.23
Gross irrigation (mm) = Net–actual irrigation/Ea (efficiency of added water)	56.26	181.65	44.14		282.04
Crop growth stage water requirement (Surface irr, mm)	112.52	181.65	44.14		338.30
Crop growth stage water requirement (Sprinkler irr, mm)	90.01	145.32	35.31		270.64
Crop growth stage water requirement (Drip irr, mm)	75.01	121.10	29.42		225.35

When investigating the alfalfa crop, which is one of the most water–consuming crop, we found via modeling that the amount of water required to be provided was 27438, 23518, 18292 m^3/ha by surface, sprinkler, and drip irrigation respectively, as in **Table 7**. When linking with the NewLoc–Clim 1.10 program, rainfall can be replaced by two irrigations in the germination and growth phases, reducing the amount of water required to be provided in the most appropriate method (sprinkling) to 20716 m^3/ha. Considering the adjusted yield (43.2 t/ha), which is much higher than one of the region's farmer and the center (11.4–18.2 t/ha), we can deduce the crop response coefficient in this type of soil, which recorded a value of 1.12, and these results were agreement with those of[19].

Table 7. Results of modeling alfalfa irrigation using AquaCrop program.

Growth Stages	Germination	Development	Flowering	1st Cut	2nd Cut	3rd Cut	4th Cut	5th Cut	Sum
Date	12/1211/–10	3/31– 12/13	4/13–4/1	6/3–4/14	7/12–6/4	8/31– 7/13	10/19–9/1	11/9–10/20	
(T), (day)	33	109	13	51	39	50	49	21	365
(RD), (m)	0.4	0.75	1.05	1.17	1.5	1.89	1.9	1.9	
(ET0), (mm/day)	1.73	1.46	1.92	7.07	7.4	7.70	4.99	2.47	
(Kc)	0.38	1.1	0.77	1.1	1.1	1.1	1.1	0.47	
ET = ET0 x Kc	21.69	174.5	19.22	396.6	317.5	423.5	268.9	24.38	1646.3
(MAD)	0.5	0.65	0.65	0.65	0.65	0.65	0.65	0.5	
TAW (mm)	73.6	138	193.2	215.3	276	347.8	349.6	349.6	1943.1
D (mm) = TAW x P	36.80	89.70	125.6	139.9	179.4	226.1	227.24	174.80	1199.45
The Number of Irrigations	1	2	1	3	2	2	2	1	14
Net–Actual Irrigation (mm)	21.69	87.23	19.22	132.1	158.7	211.7	134.48	24.38	
Gross Irrigation (mm)	36.16	145.4	32.03	220.4	264.5	352.9	224.1	40.6	
Crop Growth Stage Water Requirement (surface irr, mm)	36.16	290.7	32.03	661.1	529.1	705.8	448.3	40.63	2743.8
Crop Growth Stage Water Requirement (sprinkler irr, mm)	31.0	249.2	27.5	566.6	453.5	605.0	384.2	34.8	2351.8
Crop Growth Stage Water Requirement (drip irr, mm)	24.1	193.8	21.4	440.7	352.7	470.6	298.8	27.1	1829.2

3.2. Water Use Efficiency after the Application of the Following Strategies [Crop Rotation (Barley–Vetch/Conservation Agriculture/) and Alfalfa Fertigation]

The results of the statistical analysis showed significant differences between the treatments with regard to the actual irrigation water use efficiency (kg.m^3), where the value of the least significant difference ($LSD_{0.05}$) reached approximately 0.12. The sprinkler irrigation treatment outperformed the other treatments and recorded 1.8 kg/m^3 and 4.1 kg/m^3, followed by the drip irrigation treatment, which significantly outperformed the surface flood irrigation treatment, which recorded the lowest value of 0.9 kg/m^3 and 2.2 kg/m^3 for barley and vetch crops, respectively, after taking into account the crop response factor to water. When compared with the farms of the region, this efficiency did not exceed 0.42 kg/m^3 and 1.87 kg/m^3 for barley and vetch, respectively, despite its reliance on the sprinkler irrigation method as in **Table 8**. This is due to the lack of agricultural rotation and the conservation agriculture method, which enriches the soil with the required fertility for crop growth and increases its natural and water productivity. This was in agreement with the results of[20]. The same applies to the alfalfa crop, there were clear significant differences between the sprinkler irrigation method, which is considered one of the best methods in terms of economic feasibility and dealing with this type of forage crop, which recorded 2.1 kg/m^3 and the surface irrigation method, which amounted to 1.57 kg/m^3, and this is in the event that the crop's full requirements are provided according to the AquaCrop program and the environment of the study area, but when compared with the area's farmer, there is a huge difference in terms of natural and water productivity, which decreased to reach 0.47 kg/m^3.

Table 8. Results of Water use efficiency (Kg/m^3) using AquaCrop program.

Treatments	Barley	Vetch	Alfalfa
Sprinkler irrigation	1.80	4.10	2.10
Drip irrigation	1.56	3.45	2.0
Surface flood irrigation	0.90	2.20	1.57
Farmer of the region	0.42	1.87	0.47

By discussing and detailing the results greatly in terms of the number of days until harvest, plant height, number of branches, and yield of alfalfa crop, we found that: The irrigation strategy with the proposed fertilization was superior to the control treatment, which recorded 20.1 days, with a clear significant difference of 9.1%. This is attributed to the fact that nitrogen fertilization extends the flowering period in alfalfa and fodder barley crops, and this was agreement with those of[21]. There are also clear significant differences between applying this strategy and the farmer's method in terms of the number of branches per plant, its height, and yield, and this was agreement with the results of[22], as in **Table 9**. When these results are generalized to all the irrigated area implemented according to the percentage of the area of each crop in the region (Salamiyya) and after implementing the project of converting to modern irrigation, it is concluded that in addition to increasing production in quantity and quality, it is possible to save and save approximately 7.1 million m^3 annually when following the irrigation programming of the program compared to what is applied by the farmer. This quantity is sufficient to cover the deficit in drinking water requirements and domestic use as a first priority in the studied region, especially in very dry years. As for normal years, we will be able to save 8.1 million m^3, and from this we can ensure improving the productivity of the farms in Salamiyya and their management even after 20 years. At least, especially if suitable alternative drought tolerant crop are introduced. This is only recommended after meeting the first priority requirements (drinking water and domestic use).

Table 9. The comparison of the results of the strategy (alfalfa crop fertigation) with those of the farmers (the control).

The Strategy of Fertigation	Treatment	The Number of Days Even the Date of Cutting	Branches' Number Per Plant	Plant's Height (cm)	Yield (t/ha)
	Drip irr	27.8	14.2	83.4	43.2
	Sprinkler irr	28.2	13.2	98.2	44.1
	Surface irr	28.7	14.1	84.3	42.2
Mean		28.23	13.8	88.6	43.2
Farmer Irr (control)		20.1	8.21	44.3	13.8
Significance Ratio (%)		9.1	78.1	87.2	171
LSD0.05		1.3	1.4	3.4	0.4
CV		11.3	17.3	7.9	18.1

3.3. Strategy for Applying the Virtual Water Concept:

The virtual water principle refers to replacing crop with high water requirements and without–economic feasibility with those more profitable and less water demands, Similar data were proven by[23, 24]. The programming results of crops showed that the lowest virtual water volume (m^3/t) was in alfalfa (215.2 m^3/t), followed by vetch (433.3 m^3/t) and barley (641.3 m^3/t). By studying both the economic profit and the ratio of return/cost in the three crops, we can conclude that the profit per unit of water ($/$m^3$) was the highest in vetch (0.055 $/$m^3$), followed by barley (0.035 $/$m^3$) and then alfalfa (0.012 $/$m^3$). By partially replacing Salamiyya alfalfa crop (area: 30 ha, Program's ETc: 1646,3 mm) with the profitable barley (area: 30370 ha, Program's ETc: 307.7 mm) or vetch (area: 100 ha, Program's ETc: 316.2 mm): 0.4–0.6 MCM of irrigation water per year will be saved because the average water consumption to obtain an acceptable production of barley or vetch is equivalent to 0.19 of the average water consumption to obtain an acceptable production of alfalfa under the conditions of the studied area. Furthermore, there is saving in the cost of irrigation water according to the source, whether surface or groundwater, then obtaining a profit of 898,42 $/ha.

4. Conclusions and Suggestions

The modified AquaCrop 2012 program, along with other supporting programs such as ET_0Calc, SPAW, and NewLoc–Clim 1.10, has proven through simulation and post–calibration verification the validity of the results of the Water Measurement System (WAS), but with higher accuracy and less effort. It has demonstrated its ability to manage and increase farm productivity after applying field strategies, due to its processing of the data entered on a monthly and daily basis, which was agreement with those of[25] in the Orontes Basin. The program answered the questions coming by the farmer (When, how much, and how do we irrigate? Where do we plant the crop and how do we deal with it to get the highest return?). Hence, the best method that suits the conditions of the region was deduced to obtain the highest water productivity for the studied forage crop and similar ones, as the program balances inputs and outputs and takes into account the crop response factor, which most previous studies have ignored so far in Syria. Furthermore, it deals with agricultural water demand sites in a qualitative manner that differs from other programs, as it takes environmental aspects into consideration and links the relationship between the type of cultivated plant (growth stages), water (rain and applied irrigation efficiency), the prevailing climate (evaporation–transpiration), and the soil (its texture and available water) with the aim of achieving the best production with the least amount of water provided, as we conclude from the above study that agricultural water productivity would be improved by about 63%, 45%, and more than 120% compared to the field application followed on barley, vetch, and alfalfa, respectively. This is because the field application (control) depends on field observations, inherited personal experiences, and the periodic irrigation system, which results in significant water waste, low crop yields, and depletion of potable groundwater. While by applying the virtual water principle in the agricultural sector, which is the largest consumer of water, according to the results obtained by the program, large quantities of water will be saved, which will help renew the groundwater supply in the region and improve its water footprint.

Finally, we suggest representing the farm and describing it climatically and hydrologically before embarking on any agricultural project. Conducting a periodic survey using modern technologies from the Remote Sensing Authority. Following the concept of virtual water and alternative agriculture for crops with higher economic returns and lower water requirements to avoid water deficit in dry and very dry years.

Author Contributions

Y.T. and A.A. conceived of the presented idea. K.B. and Y.T. put the methodology. Y.M. and Y.T. developed the theory and performed the computations. Additionally, they did formal analysis and send the work to A.A. and K.B. to validate. Y.M. gave Y.T. much data to curate it. Furthermore, Y.T. prepared an original draft. K.B. contributed to sample preparation. A.A. supervise the work. Y.T. manage all the processes without funding. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the basics of research and urgent need of area to work out some problems, and approved by the ANRR and GCSAR, Syria." This research had had a number and a date in ANRR research plan from 2014 to 2017.

Data Availability Statement

Statistical plan of MAAR in Syria. GCSAR data, field results data. measured data and libraries of the used programs. All those data are documented in the references below.

Conflicts of Interest

The authors declare no conflict of interest.

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