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Optimum Returns from Greenhouse Vegetables under Water Quality and Risk Constraints in the UAE

Eihab Fathelrahman [1,*], Mohamed Gheblawi [1], Safdar Muhammad [1], Emily Dunn [1], James C. Ascough II [2,†] and Timothy R. Green [3]

1 Department of Agribusiness and Consumer Sciences, College of Food and Agriculture, United Arab Emirates University, Al Ain 009713, UAE; gheblawi@uaeu.ac.ae (M.G.); smuhammad@uaeu.ac.ae (S.M.); emishea@uaeu.ac.ae (E.D.)
2 USDA-ARS, 1400 Independence Ave. S.W., Washington, DC 20250, USA
3 USDA, Agricultural Research Service (ARS), Water Management and Systems Research Unit, Fort Collins, CO 80521, USA; tim.green@ars.usda.gov
* Correspondence: eihab.fathelrahman@uaeu.ac.ae
† The fifth author is deceased.

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Abstract: Greenhouses have been used in the United Arab Emirates (UAE) to produce vegetables that contribute toward UAE food security, including offering fresh vegetable produce in the off-season. However, to manage such greenhouses, farmers face both technical and environmental limitations (i.e., high water scarcity), as well as vegetable market price instability. The objective of this study is to explore tradeoffs between returns (i.e., gross margin) of selected vegetables (tomato, pepper, and cucumber), risk (deviation from gross margin means), and an environmental constraint (water salinity) using a unique target MOTAD (minimization of total absolute deviations) approach to support UAE farmer decision-making processes. The optimal target MOTAD solution included all three vegetables and no corner solution. The results showed tradeoffs between returns and risks, and confirmed that product diversification reduces overall risk. The analysis was consistent with farmer perceptions based on a survey of 78 producers in the region. The search for the optimal mix of vegetable production under UAE greenhouse conditions revealed that reduction in tomato production should be offset by an increase in cucumber production while maintaining a constant level of pepper production. In other words, risk is reduced as cucumber production increases due to the high level of tomato and lettuce price volatility as the alternative to cucumber. The results also demonstrated the importance of the water salinity environmental constraint, as it was found to have a positive marginal value in the optimal vegetable mix solution (i.e., important factor). Thus the optimal solution was highly sensitive to changes in the crop water salinity constraint. The study results also demonstrate that the target MOTAD approach is a suitable optimization methodology. As a practical approach, a decision-maker in the UAE can consider gross margin (total revenue-variable costs) maximization with risk and water quality constraints to find the optimal vegetable product mix under greenhouse conditions.

Keywords: target MOTAD; optimization; risk; tradeoffs; water salinity; vegetables; greenhouses; crop production

1. Introduction

Crop production in the United Arab Emirates (UAE) faces several land, water, and management challenges. Vegetable production under greenhouse conditions offers an alternative to growing crops in open field conditions. However, the production of greenhouse vegetables presents its own challenges that stem from farming in predominantly arid UAE land conditions. These challenges include the need for proper management and control of limited water resources under typical land, capital, and labor scenarios, as well as environmental constraints. The main environmental constraints a UAE farmer must face are farm water problems, specifically water scarcity and high levels of salinity in the available water [1]. In 2012, the total value of domestically-produced vegetables in the UAE was estimated to be 364 million Arab Emirates Dirhams (AED) by the (Ministry of Water and Environment, 2014 [2] or approximately $100 million USD (using an exchange rate of 1 USD = 3.65 AED).

A large majority of the vegetable farming takes place in the Abu Dhabi Emirate. UAE Bureau of Statistics (2013) data showed that about 1547 out of 3941 hectares (or ~40%) of the total vegetable area cultivated in the country are located in Abu Dhabi. Abu Dhabi Food Control Authority (ADFCA) statistics showed that 4370 out of 10,003 (or 44%) of the greenhouses in Abu Dhabi Emirate were designated as non-active as of 2010–2011 by ADFCA, 2014 [3] (see Table 1).

Table 1. Distribution of the number of active and non-active greenhouses in Abu Dhabi by region in 2010–2011.

Region	Number of Active Greenhouses	Area of Active Greenhouses (ha)	Number of Non-Active Greenhouses	Area of Non Active Greenhouses (ha)	Non-Active Greenhouses (%)	Non-Active Area (%)
Abu Dhabi	347	14.4	373	18.1	52	56
Western Region	3164	100.9	287	8.7	8	8
Al Ain	2122	85.9	3710	109.5	64	56
Abu Dhabi Emirate	5633	201.2	4370	136	44	40

Source: Abu Dhabi Food Control Authority (ADFCA); (2014), Statistic Book for Year 2011 [3].

The greenhouse farms face technical and market constraints, including irrigation, water quantity and quality, output price instability, and increasing operational costs. Possible causes for non-active status and abandonment of greenhouse farms in the UAE include a lack of effective management, insufficient groundwater, and/or high groundwater salinity. The significant challenges mentioned above greatly impact farmer decision-making and selection of vegetable product mix in the UAE, and in the Abu Dhabi Emirate in particular. The UAE farmer, utilizing the greenhouse systems, will seek to optimize limited resources through maximizing gross margins and minimizing the greatest sources of risk found in the UAE agricultural sector, i.e., water scarcity and high levels of water salinity [1].

This study utilizes a target MOTAD (minimization of total absolute deviations) approach to quantify tradeoffs between returns, risk, and environmental constraints. Several studies have employed MOTAD methodology to find the optimal distribution of water and or vegetables at the farm or sector level. Haddad et al. [4] utilized a MOTAD model that maximized expected net farm returns subject to parameterized irrigation water deficiencies of 30% and 50% of the normal availability and deviations around the mean gross margin using a three-year moving average. The results showed less sensitivity to risk during winter months where rainfall reduces dependence on supplementary irrigation. Boustani et al. [5] applied a target MOTAD with a minimum variance approach to develop risk-minimizing cropping patterns associated with different levels of income, while parameterizing water consumption. The results pointed to tradeoffs among water use, reduced risk, and achieving specific gross margins. Price support programs seemed to affect cropping patterns of wheat. Al-Karablieh et al. [6] developed three MOTAD models in order to derive risk efficient farm plans under sets of water and land constraints. Water was found to constrain increments in expected income; however, model results showed over-utilization of water in the study area. The model with a three-year unequally-weighted moving average about the mean of historical gross margin yielded risk-efficiency frontiers with lower standard deviation and variability at the same expected income levels. Umoh [7] used a target MOTAD model to determine an optimum farm plan incorporating risk factors in the wetlands of Nigeria. Vegetable crops were found to carry the most risk, while a combination of cassava, maize, and other crops seemed to be less risky.

In order to account for risk in a decision framework, Zimet et al. [8] developed a target MOTAD model incorporating potential competition and complementarity among crop and beef cattle enterprises. Cow-calf production functioned as a stabilizer of income since it entered the optimal solution when accounting for the fluctuations of returns. Lu et al. [9] analyzed Chinese small-scale farmer responses to agricultural risks with a MOTAD model application. Farmers were found to be risk adverse when the ratio of farm to total income was low. At higher levels of risk, farmers tended to employ more capital than labor, implying a higher opportunity cost of the latter. Alternative farming systems for the central Punjab region of Pakistan were analyzed by Zia [10] who found that target MOTAD efficiency frontiers were consistently above MOTAD efficiency frontiers and always generated higher expected income with fewer negative deviations than those in the corresponding MOTAD solutions. Furthermore, the target MOTAD solutions seem to suggest more specialization in crop production. Salarpour et al. [11] used a Target MOTAD model to empirically minimize the risk associated with agricultural production under drought conditions. The results showed that the optimization of farming patterns and irrigation water allocation can significantly assist in the sustainability of water resources and reducing the impact of drought. Novak et al. (1990) used target MOTAD with modified specifications to assess the risk and returns of sustainable cotton crop rotations. Datasets were collected from Auburn University experimental farms and the study analyzed rotations (two-, three-, and 10-year) of continuous cotton, with and without winter legumes. Novak et al. [12] included sustainable agriculture as an additional objective within the target MOTAD problem structure. Parton and Cumming [13] developed a target MOTAD model for use in consulting work with farmers who are under financial pressure. The authors conducted analysis of downside risk and introduction of a trade-off between financial and business risks. Berbel [14] proposed a target MOTAD-based multi-criteria approach for dealing with risk when modelling an agricultural system and concluded that the model could be used to study the trade-offs between profitability (expected returns) and risk. Mapp [15] studied the impact of production changes on income and environmental risk in the Southern High Plains in the US and used target MOTAD model to model risk from nitrates and pesticides. Norton and Hazell d [16] described how target MOTAD can be set up to maximize expected income (e.g., gross income) subject to achieving a satisfactory level of compliance with targeted income that minimizes mean absolute gross margin deviation. Romero and Rehman [17] proposed an iterative process using a target MOTAD model and minimized gross margin deviations from the mean value to illustrate the tradeoff between income and risk. In general, most of the above studies modified target MOTAD in a specific format to address multiple objectives at the sector or farm level including the objective of risk minimization.

The present study extends the target MOTAD framework and empirical results for simplified multi-dimensional optimization using Microsoft Excel©, Microsoft, Redmond, Washington, United States which is well-tested and -documented for greenhouse production under economic optimization, risk, and environmental constraints simultaneously under the UAE arid land greenhouse production conditions. The expanded linear programming (LP) model to include risk analysis in the target MOTAD model in this research finds the optimal solution of greenhouse production and inputs used (e.g., value of seed, fertilizer, fuel, and labor). The main advantage over a typical LP model is the flexibility to include new assumptions, such as consideration of deviation from the mean technical and environmental constraints and their coefficients in the model (i.e., risk and environmental constraints and their coefficients, respectively). The scientific contribution to this optimization process, in order to address this research objective, is considering the field level environmental constraint (i.e., water salinity) as detailed in the methodology section below. In the LP and the target MOTAD models, when the optimum solution is obtained, the binding constraints and marginal values of such a solution are estimated for each constraint. A binding constraint is a constraint used in target MOTAD equations whose value satisfies the optimal solution; any changes in its value changes the optimal solution of vegetables mix. A binding constraint indicates that a salinity threshold level has been reached in the optimum solution. Further reductions in salinity would require a new optimal solution in terms of the fractions of vegetables produced.

The primary objective of this study is to explore the tradeoffs between returns (i.e., gross margin) from vegetable (i.e., tomato, pepper, and cucumber) production, a water salinity constraint (described below), and risk (i.e., deviation from the gross margin means) using a target MOTAD approach. This approach represents a three-dimensional investigation of the optimal vegetable mix within the tradeoff framework. Furthermore, the tradeoff framework was expanded to include a critical environmental constraint for arid land conditions (i.e., not exceeding a water salinity irrigation threshold) in order to test the significance of such constraints in the search for the optimal vegetable production mix.

2. Methodology

2.1. Target MOTAD

The target MOTAD optimization method was first proposed by Tauer [18]. The following is the UAE greenhouse optimization target MOTAD model used in this study:

$$\text{Maximize}E\ (Z) = \sum_{j=1}^{n} c_j x_j \tag{1}$$

subject to:

$$\sum_{j=1}^{n} a_{kj} x_j \leq b_k,\ k = 1, m \tag{2}$$

$$T - \sum_{j=1}^{n} \mathrm{c}_{rj} \mathrm{x}_j - y_r \leq 0,\ r = 1, s \tag{3}$$

$$\sum_{r=1}^{s} p_r y_r = \lambda,\ \lambda = M \to 0 \tag{4}$$

where:

$E(Z)$ is the expected return of the plan of activities from j to n, and
x_j is the level of such activity, all x_j and $y_r \geq 0$;
c_j is the expected gross margins of tomato, cucumber, and pepper production in this study;
a_{kj} is the technical requirement of activity j for resource or constraint k (i.e., input-output coefficients);
b_k is the level of resource or constraint k where the constraints in this study are labor, seeds, fertilizer, electricity, and water salinity;
T is the target level of return, where three levels are simulated to:

(1) cover total cost,
(2) secure 10% return on operational costs, and
(3) secure 15% return on operational costs;

c_{rj} is the return of activity j for observation r;
p_r is the probability that observation r will occur;
y_r is the deviation below T for state of nature/alternative of observation r;
λ is a constant parameterized from M to 0, and M is a large number;
m is the number of constraints and resource equations; and
s is the number of observations.

As stated above, target MOTAD was used to identify an optimum combination of fresh greenhouse vegetables (tomato, pepper, and cucumber) when the expected returns (i.e., gross margins) from production of the selected vegetables was maximized, subject to maintaining selected minimum targeted levels (six scenarios) of minimized absolute deviation (MAD) from the base scenario level of risk; an example of gross margin targets obtained are included in Tables 2 and 3 below and constraint numerical levels.

Table 2. Target MOTAD table for green house production in United Arab Emirates Tableau.

	CU	TOM	PEP	Z1-	Z2-	Z3-	Z4-	Z5-	Z6-	Maximum Total Profit		Constraint Level
Vegetable produced (kg per greenhouse)	8545	7119	6460	0.00	0.00	0.00	0.00	0.00	0.00			
Expected gross margin per unit produced	1.601	1.255	1.853							34,585.27		
Land	1	1	1							22,124	≤	23,000
Labor (Dhs per kg produced)	0.117	0.086	0.132							2464.719	≤	3000
Fertilizer (Dh)s	0.171	0.107	0.149							3185.468	≤	3000
Electricity (Dhs)	0.228	0.212	0.578							7191.368	≤	7000
Seeds (Dhs)	0.039	0.036	0.168							1674.819	≤	1600
Salinity (EC)	0.099	0.114	0.065							2083	≤	2000
Rotational requirement	−1	1	−1							−7886	<	0
Expected shortfall from target				0.167	0.167	0.167	0.167	0.167	0.167	0	=	0
Risk rows												
Dev1 (Dhs)	0.785	0.576	0.925	1						16,786.745	≥	20,000
Dev2 (Dhs)	0.683	0.667	0.943		1					16,675.134	≥	20,000
Dev3 (Dhs)	1.215	0.762	1.485			1				25,393.402	≥	20,000
Dev4 (Dhs)	1.333	0.722	0.942				1			22,619.3	≥	20,000
Dev5 (Dhs)	1.395	0.843	1.669					1		28,698.459	≥	20,000
Dev6 (Dhs)	0.796	1.024	1.010						1	20,615.23	≥	20,000

Where CU = cucumber; TOM = tomatoes; PEP = pepper; Zi are the slack variables; and Dvi are the deviates from the mean, Dhs = Dirham, the United Arab Emirates currency.

Table 3. Target MOTAD gross margin and vegetable production mix for the base and five selected risk level scenarios.

Scenario	Gross Margin (AED)	Difference from the Base (%)	Risk Level (AED)	Production per Greenhouse					
				Tomato Production (kg)	Tomato Production Difference from the Base (%)	Pepper Production (kg)	Pepper Production Difference from the Base (%)	Cucumber Production (kg)	Cucumber Production Difference from the Base (%)
Base	34,745	-	15,000	8511	-	8057	-	1039	-
1	34,682	−0.2%	14,000	8346	−1.9%	8054	0.0%	1204	15.9%
2	34,619	−0.4%	13,000	8182	−3.9%	8051	0.0%	1369	31.8%
3	34,566	−0.5%	12,000	8017	−5.8%	8048	0.0%	1534	47.7%
4	34,494	−0.7%	11,000	7852	−7.7%	8045	0.0%	1699	63.6%
5	34,431	−0.9%	10,000	7687	−9.7%	8042	0.0%	1864	79.4%

2.2. Farmer Survey

In 2013, the authors conducted a survey in order to gather information regarding greenhouse production in the Abu Dhabi Emirate. Table 4 summarizes selected descriptive statistics by vegetable type (i.e., tomatoes, peppers, and cucumbers) across the Emirate's three regions: Western, Abu Dhabi, and Al Ain. The survey included both face-to-face interviews with farm owners and/or managers, as well as telephone surveys of 78 greenhouse farms. Survey questions were primarily related to greenhouse production quantities and resource use (i.e., labor, inputs, electricity, and water quantities) in 2012. The survey's questionnaire section also included several questions related to water salinity levels and farm gate prices of produced vegetables (farm gate price is the retail price minus all costs of delivering the product from the farm to the consumer).

Table 4. Survey statistics of 2012 greenhouse production in the Abu Dhabi Emirate.

Crop/Statistic	Quantity of Production (kg)	Price (AED kg^{-1})	Total Revenue (AED)	Variable Cost (AED)	Gross Margin (AED)
Tomatoes					
Mean	128,167	2.5	297,158	93,738	203,420
Median	46,500	2.8	130,500	39,670	88,339
Maximum	800,000	5.0	1,600,000	468,000	1,132,000
Minimum	18,000	0.8	14,400	13,579	−16,940
Standard Deviation	219,516	1.1	447,822	126,492	323,105
Peppers					
Mean	132,667	3.2	388,667	84,159	318,702
Median	106,000	3.0	364,500	76,188	214,600
Maximum	324,000	4.0	972,000	153,120	1,172,025
Minimum	36,000	1.5	126,000	32,200	−6140
Standard Deviation	89,601	0.7	229,664	33,572	271,897
Cucumbers					
Mean	185,375	2.1	434,375	112,115	263,437
Median	139,500	2.0	265,500	84,385	154,600
Maximum	660,000	3.0	1,980,000	277,720	1,702,280
Minimum	60,000	1.5	108,000	55,400	−6520
Standard Deviation	169,072	0.4	522,521	66,437	327,272

The data obtained from the survey were tabulated and summarized to explore the variability of selected indicators, crop production levels, farm gate prices, total revenue, variable costs, and gross margins for the vegetable production activities. The collected data was also used to estimate the coefficients required for the linear programming tableau (Table 2) including the objective function, the input-output coefficients, and right-hand side (RHS) constraint parameters for the research base and risk simulations as described in the Methodology section of this paper.

The survey identified significant challenges that greenhouse owners and managers in the Abu Dhabi Emirate face with respect to production decisions. The challenges included output price volatility, water scarcity, and the impact of water salinity. The highest number of respondents (75 out of 78 farmers, or 96% of the sample) reported that low output farm gate prices represent a significant challenge to farm operations management. The second-most important issue reported by survey respondents was a high level of water salinity (24 farmers, or 31%). Thirty six farmers (46%) indicated that their farm owns and operates a desalination unit. The respondents indicated that the average purchase cost (capital cost) of the first desalinization unit they purchased was about 109,343 AED. The average capacity of the desalination units was approximately 40,971 gallons (1 gallon = 3.785 L for the first unit purchased. Six farmers (8%) indicated that they operate multiple desalination units in their farms. These respondents showed that the average capacity of their desalination unit is about 46,667 gallons for the first unit they purchased. Eleven farmers (14%) responded that they install their surface desalination unit at the irrigation system level. Twenty-two farmers (28%) indicated that they install the desalination unit at the well (attached to the well motors). Fifty-two farmers (67%)

felt that water salinity impacts greenhouse vegetables productivity. Eight farmers (10%) indicated that they experience up to 25% productivity loss due to high salinity levels, and one farmer indicated that the level of productivity loss is approximately 26%–50% due to water salinity. Sixty-nine farmers (88%) indicated that they do not know the impact of the water salinity on vegetable production. These survey results reveal the importance of water salinity constraint in greenhouse vegetable production in the UAE. About 27% of the survey respondents (21 out of 78) indicated that water scarcity was a significant challenge that negatively impacted farm productivity when managing the farm resources.

2.3. Water Salinity Constraint

Water salinity imposes a restriction on the production of fresh vegetables under greenhouse conditions because too much salt from groundwater and treated water supplies can reduce, or completely prevent, vegetable production. Conversely, too little salt can reduce water infiltration, which can also reduce water use efficiency. Thus, understanding water salinity and its potential negative impacts on vegetable growth is very important with respect to avoiding problems and optimizing production. To assess the importance of such constraint-specific relevant questions to the impact of salinity on greenhouses production in the study area were included in the survey (see Appendix A). Abu Hadid [19] emphasized that the availability of water (in sufficient quantity and of good quality) is an essential requirement for growing high added-value crops in greenhouses. Agricultural farmland has been abandoned in the UAE due to the lack of water in sufficient quantities and of acceptable quality (salinity). Soluble salts in water are measured by electrical conductivity (EC), also referred to as specific conductance or salinity, and expressed as millimhos per centimeter (mmhos cm^{-1}) or, equivalently, milliSiemens per centimeter (mS cm^{-1}). In the UAE, high EC occurs in farms from water contaminated by road salt and from saltwater intrusion in coastal wells. Irrigation water, to which water-soluble fertilizers are added, has an EC of about 1.5–2.5 mS cm^{-1}. To avoid plant injury, the untreated water should have an EC no higher than the acceptable range of 0–1.5 mS cm^{-1}, so less than 1 mS cm^{-1} is recommended. Excess soluble salt impairs root function, which can lead to reduced water uptake and nutrients deficiencies (Cox, 2010). In this study, the EC thresholds for the vegetable water salinity coefficients for each crop were set for greenhouse production under arid land conditions based on the authors' personal communication with an agronomy expert. The six scenarios in this research simulated in the absence of the environmental constraint (i.e., water salinity) in order to explore the difference in the total gross margin, optimum vegetables mix, and the tradeoffs between income and risk, on one hand, and between risk and the environmental constraint, on the other hand.

3. Results

The target MOTAD model, as described in the methodology section and illustrated in Table 2, was used to identify the optimum mix of vegetables under greenhouse conditions in the UAE. The target MOTAD model scenarios represent deviations from the mean gross margin by vegetable production, as indicated by the risk level (Table 3). The base model optimization solution results indicated that all three vegetables (tomatoes, cucumbers, and peppers) appear in the final results (Table 3). The results indicated that four constraints, namely labor cost, seed cost, water salinity, and the risk constraints, were binding constraints. Meanwhile, other constraints, such as land, fertilizer cost, and electricity cost, were found to be non-binding constraints. A non-binding constraint is a constraint where further change in its value does not necessarily cause a change in the optimum solution results for production value, resource use, or gross margin.

The shadow prices of labor cost, seeds cost, and the risk constraints were found to be 11, 8, and 0.35 AED, respectively. The shadow price is defined to be the marginal value product of the corresponding resource or the dual value of the binding constraints. In other words, the shadow price is the change in the value of the objective function (i.e., total gross margin) if the corresponding binding constraints are changed by one unit. The shadow prices revealed in this model reflect a relatively higher scarcity of resources/constraints at the optimum vegetable mix level when gross margin is maximized and the risk constraint is considered. This was compared to other constraints that were found not to be binding constraints, such as land, fertilizer cost, and electricity cost. For example, the labor cost constraint shadow price of 11 AED was the marginal value of the labor resource. In other words, a one-unit increase in the labor supply would allow an additional 11 AED to the gross margin.

The tradeoff between returns and risk were explored by simulating six scenarios (the base plus five scenarios) illustrating various levels of risk. This was implemented in order to identify the corresponding gross margin changes due to changes in risk measured by considering the total absolute deviation from the average gross margin. All scenarios were simulated as a gross margin maximization problem subject to all constraints described above, including the risk constraints. Table 4 shows that for the various risk level scenarios, the production of tomatoes declined in the product mix as the risk level was decreased. Conversely, the production of cucumber increased in the product mix as the risk level was decreased. Furthermore, pepper production was maintained at a fairly constant level of production. This was due largely to the relatively higher tomato farm gate price variability compared to pepper and cucumber farm gate price variability (Table 4). The standard deviation of tomato prices was found to be 1.1 AED kg^{-1}, compared with 0.7 AED kg^{-1} and 0.4 AED kg^{-1} of pepper and cucumber, respectively.

The target MOTAD base optimization simulations indicated, at the optimum level, a typical greenhouse farm would produce 8511 kg of tomatoes, 8057 kg of peppers, and 1039 kg of cucumbers. The optimal product mix changes at each of the five selected levels of risk represented by varying summation of the absolute deviation of the gross margins. These levels were selected at the range between 15,000 AED, in the Base scenario, to 10,000 AED in Scenario 5, using 1000 AED increments for each scenario between the Base scenario and Scenario 5 (Table 3). Table 3 reveals that no large change occurred for pepper production between the Base and the other five scenarios. However, the simulations/scenario results show that as the level of risk increased, the production of cucumber also increased. The changes in the cucumber production, at the optimum vegetables mix, indicate that the product mix favors more cucumber production, due to its relative price stability at the farm gate level compared to the other two vegetable products (tomatoes and peppers) (see Table 4). The target MOTAD results showed that the salinity constraint was a binding constraint due to the fact that their coefficients' values satisfy the optimal solution and results show positive shadow prices. Any changes in such constraints change the optimal solution of vegetable production mix. The shadow price of the salinity constraint indicated the high importance of such an environmental constraint in formulating the optimum mix of vegetables production under greenhouse conditions in the UAE.

To consider the environmental constraint of water salinity, the salinity coefficients were calculated and estimated to be 0.886, 0.901, and 0.931 ECe dS m^{-1} per unit produced of tomato, cucumber, and pepper, respectively. ECe is the electrical conductivity of the saturated paste [20]. The estimated thresholds indicate that tomatoes are more tolerant to water salinity compared to cucumbers and peppers. Cox [21] recommended that farmers and vegetable greenhouse operators have irrigation water laboratory tested for pH and alkalinity. Reclaimed water, runoff water, or recycled water may require reconditioning before use for irrigation. This is due to the possibility that water is contaminated with disease-causing organisms, soluble salts, and traces of organic material. Considering such important water quality management is critical for optimal greenhouse irrigation water management.

To explore the impact of relaxing the water salinity constraint, the gross margin was simulated at selected risk levels and subject to satisfying the water quality threshold constraint (see Table 5 and the scenario results in Figure 1). When the water salinity constraints are relaxed, the results obtained from this exercise illustrated the impact of a third dimension to the tradeoff analysis between return and risk. The third dimension analysis results were due to adding the environmental constraint (i.e., the water salinity constraint). This was illustrated by the upward shift in the tradeoff curve in Figure 1, found in the total gross margin curve between each pair of gross margins. In other words, the water salinity constraint impacted the gross margin levels, and there was evidence of interaction between risk level in the results and the water salinity levels. The shift was not a parallel shift between each pair of the gross margins shifting from the baseline of the five selected scenarios. The cross-hatched area in Figure 1 illustrates the tradeoff between the risk constraint and the environmental (i.e., the water salinity) constraint.

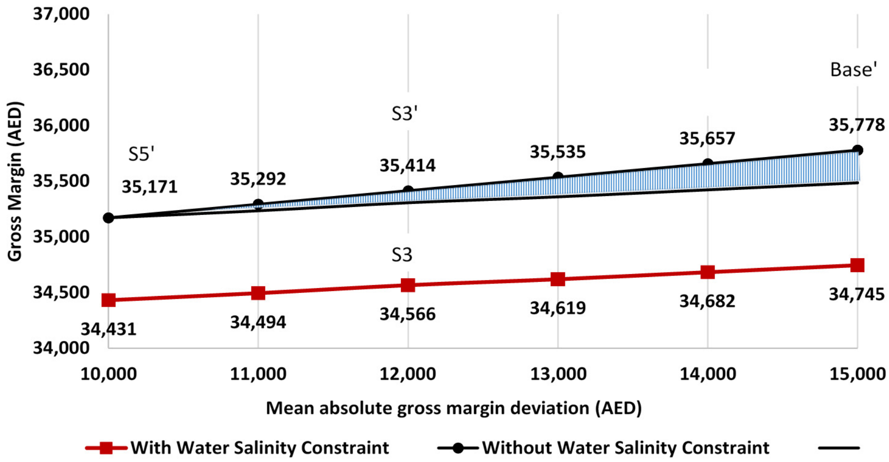

Figure 1. Trade-off between gross margin, mean absolute gross margin deviations (risk levels), and environment (water salinity) constraint, where S and S′ are the scenarios.

In summary, there was evidence of a strong tradeoff between the gross margins (total revenue–variable costs) and risk, on one hand, and between gross margin and the environment constraint on the other. Furthermore, there was evidence of interaction between the risk and the environmental constraint at the high levels of risk constraint. The differences between the gross margins pair increased as the risk level increased. The difference was reported to be only 739 AED ha^{-1} when the risk level was set at 10,000 AED. However, this difference increased to 1033 AED when the risk level was increased to 15,000 AED (see Figure 1 and Table 5).

Table 5. Gross margin, vegetables production mix, and tradeoff between risk and environmental constraint.

Scenario	Risk Level (AED)	Gross Margin (AED)	Tomato Production (kg)	Cucumber Production (kg)	Pepper Production (kg)	Gross Margin Differences with and without Salinity Constraint (AED)
Base	15,000	35,778	9109	1604	7806	1033
1	14,000	35,657	8910	1737	7806	975
2	13,000	35,535	8712	1870	7818	916
3	12,000	35,414	8513	2003	7830	848
4	11,000	35,292	8314	2136	7842	798
5	10,000	35,171	8115	2269	7853	739

The implications of the research findings are two-fold. First, the results indicate the validity of the augmented target MOTAD (with the environmental constraint) methodological approach to address scarce resource allocation, especially when the environmental constraints are binding. Second, the research findings show that management and control of vegetable production under UAE greenhouse conditions can be beneficial (when identifying the optimum mix of vegetables produced) if the search for such a mix includes not only gross margin at a targeted level of income but also other important constraints as described herein. The constraints included in this research were assumed to be both technical constraints (representing land, inputs use, and environmental constraints), and environmental constraints (i.e., water salinity) that were considered in this research was found to be a significant, especially under such arid land conditions found in the UAE, as a high level of risk factor (Table 5, Figure 1).

4. Summary and Conclusions

In this study, the target MOTAD search for the optimum vegetable mix revealed that all three vegetables considered (i.e., tomatoes, pepper, and cucumber) enter into the optimum solution that maximizes returns under the selected resources and risk constraints. This indicates that the optimum mix solution encourages the inclusion of all three of the crops and, thus, discourages any form of "corner solution" that may eliminate one or more vegetables. This is consistent with the general (real-world) principle that a decision-maker (DM) would consider diversification in order to mitigate negative economic or technically-adverse events that may affect one product by enhancing a possible positive economic or technical outcome of other products.

The results of this research confirmed survey results of Abu Dhabi Emirate greenhouse farmers where respondents showed concern about both instability of farm gate prices and high salinity when making production decisions. Target MOTAD optimization results reveal that a typical greenhouse vegetable producer would annually produce 8511, 8057, and 1039 kg of tomatoes, peppers, and cucumbers, respectively. The vegetable production quantities were reduced when higher selected levels of risks were introduced into the analysis. Research results showed a higher reduction for tomato production relative to pepper and cucumber production under higher risks for greenhouses in the UAE. This was largely due to higher tomato price instability at the farm gate level. The research results also showed the presence of tradeoffs between returns and risk on one hand and between risk and environmental constraints on the other. An optimal mix of fresh vegetables produced is sensitive to the water quality constraint when such a constraint is considered as a DM objective to be considered in the optimal solution. All of these results signify that the DM, when planning for greenhouse production and marketing, should consider the importance of technical, economic, and environmental limitations. Furthermore, the salinity binding constraint indicates that a satisfactory salinity level has been reached in the optimum solution, and no further changes can be reached without changing the optimum solution of vegetable production. Furthermore, looking beyond stochastic frontier analysis for long-term analysis is to be considered.

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Appendix A. Survey Section Questions in Relationship to Greenhouses Salinity

Is your greenhouse vegetable production affected by salinity? (Yes, No, I don′t know)

If Yes, approximately what percentage of productivity deficiency can be attributed to salinity:

Impact of Salinity 10%

Impact of Salinity 11%–25%

Impact of Salinity 26%–50%

Impact of Salinity 51%–70%

Impact of Salinity more than 70%

Did your farm abandon any crop due to salinity? (Yes, No, I don′t know): Explain

Do you carry out water and soil salinity testing at your farm? (Yes, No, I don′t know why needed)

If Yes, What were the latest testing results:

Water Salinity Level (dS/m)

Soil Salinity Level (dS/m)

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