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Modeling crop cultivation pattern based on virtual water trade: evidence from Marvdasht in southern Iran

M. Bakhshoodeh, H. Dehghanpur*

Department of Agricultural Economic, College of Agriculture, Shiraz University, Shiraz, I. R. Iran

* Corresponding Author: hdehghanpur@gmail.com

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ABSTRACT- This study aims to model optimal cultivation pattern based on the maximization of importing virtual water and social net income of major crops in Marvdasht, Iran. For this purpose, a linear programming model was developed considering constraints of virtual water and land limitations followed by other models to include employment restrictions. Based on the findings, wheat and tomato were recognized as optimal products for the region. Regarding the virtual water imports, wheat has an advantage over tomato while the production of tomato needs a relatively considerable number of workers which leads to the improvement of employment in the studied areas.

INTRODUCTION

Virtual water, defined as water used for producing one unit of agricultural product, is a criterion and fundamental tool for the real consumption of water in a country for agricultural products (Allan, 1997). The volume of virtual water for destined countries may be equally measured as the amount of water needed to domestically produce imported agricultural products. Since transferring a huge amount of food is easier than transferring a huge volume of water, the global exchange of fundamental commodities is a way to balance water resources in countries facing water shortage. Virtual water along with local or indigenous water secures water requirements on national level (Allen, 1997).

The exchange of virtual water inside and/or among the countries, and even among the continents, can be considered as a tool for increasing the efficiency of water consumption on the global level, achieving water security in regions with water shortage and removing environmental limitation by determining suitable places for production (Turton, 2000). This is a way to achieve food security by purchasing a part of the required food rather than using the limited resources of water for producing all kinds of food internally (Wichelns, 2001). Considering the volume of virtual water recorded in food importation of countries with water shortage, a closer relation is observed between water retaining and dependency on food importation (Oki et al., 2001). Virtual water puts agricultural and economical concepts together with focus on water as a key agent in production (Wichlenz, 2001). Therefore, a region, a province, or a country that specially has intense fluctuation in raining and atmospheric change can remarkably reduce its water consumption by importing a part of food rather than producing all required food internally. This fact forms the main infrastructure of virtual water approach that encourages food exchanging as a way to promote efficiency of water consumption and to balance water resources in low water regions and countries for saving water in national and international levels. According to the fact that food production needs much more water than drinking and hygienic services (Zehnder and Rehler, 2002), exchanging agricultural products is considered as a useful mechanism to redistribute high volume of water and save it in importing countries (Delgado et al., 2003).

Considering virtual water as a vital criterion for the optimal use of water resources and decreasing its waste and losses mainly in arid and semi-arid countries such as Iran where efficiency of water consumption is typically very low and farming depends mainly on irrigation and to prevent over pressure on water resources in such countries, products with lower water requirements are much more efficient than using the rare water resources to produce products that need a high volume of this resource.

To determine an optimal cultivation pattern, many studies have focused on low water consumption in farms, risk-taking influence on production, pricing effect, water qualification effect, proportional advantage and seasonal planting as the objectives of their models (Howary and Azaiz, 2001; Benly and Kedul, 2003).

Although such studies offer those products with high profitability and lower water consumption, selecting optimal planting model based on the criterion of virtual water seems to be essential in water demand management. This not only improves region-planting patterns but also enhances agricultural products trade.

Although the subject of virtual water is mainly a concern on the country level, because of the existence of expanded watershed basins in the country, this study focuses on examining the cultivation pattern in Marvdasht basin in Fars province, Iran, which is well-known enough for its share in total agricultural production in the country.

In this research, first, the volume of virtual water is calculated for selected agricultural main products of the selected region including wheat, barley, rice, potato and so on. Then, an optimal pattern of cultivation is determined by applying liner programming models that are based on the volume of virtual water of the products as well as on the employment restrictions.

MATERIALS AND METHODS

In order to calculate the volume of virtual water for studied agricultural products, the amount of consumed water of individual products (CWU) is calculated at the first stage through Eq. 1 and then the ratio of water consumed by its corresponding yield (Eq. 2) is used for the determination of the amount of virtual water consumption (VWC) of that product.

$$CWU_{jti}=ET_{aijt}/Efficiency \quad (1)$$

$$VWC_{ijt} = \frac{CWU_{ijt}}{Yield_{ijt}} \quad (2)$$

where VWC_{ijt} is the amount of virtual water of crop i in area j at year t measured in m^3/kg and ET_{aijt} is water requirement of crop i in area j at year t in m^3/ha. Water requirement is the amount of water needed by the plant in an agricultural period (Farshi et al., 1997).

$Yield_{ijt}$ is the yield of crop i in area j in year t measured in kg/ha and* CWU is the amount of crop i consumption water in area j at year t in m^3/ha obtained from Eq. 1.

Efficiency stands for the efficiency of irrigation that varies based on various irrigation methods. On average, the efficiency of different kinds of irrigation method considered in this study was 36% (The Iranian Agriculture Ministry, 2003).

The required water of a crop varies each year due to different weather conditions; however, because of the lack of needed data, it was assumed to remain unchanged over the studied years.

The objective function in this model has two parts. (Eq. 3). While the first part exhibits maximization of social benefits, the second part is designed to show maximum income resulting from net imports of mentioned products into the basin. Thus, the structure of the model in this study is:

$$Max: \sum Y_i\left[(SP_i - SC_i) - VWC_i \times P_w\right] \times X_i + \sum P_i \times NM_i \quad (3)$$

Y_i is the yield of product i, C_i is internal consumption of i product, SP_i is social value or shadow price of product i in the region that is calculated by adjusting global price of the products in local currency (Rial), SC_i stands for social costs of unit production of product i in the region excluding water costs, X_i is the total area under cultivation of product i, NM_i is net imports of product i, VWC_i is the amount of virtual water, which equals that for one kilogram of gained product i (based on cubic meter/ kg) and $\overline{W}$ is the total amount of water available in the region. P_w exhibits social cost per cubic meter of water.

The model has three constraints for land, water and trade balance. Since the lands under cultivation are equal to a certain amount as $\overline{X}$, so the land constraint appears as (Eq. 4).

$$\sum_{i=1}^{n} X_i \le \overline{X} \quad (4)$$

The volume of water used in the region is given at $\overline{W}$ and includes underground, canal and river waters. The amount of water used in each hectare is obtained from the amount of virtual water multiplied by product yield. The total amount of water used within the region is also obtained by summing water consumption of all products. The water constraint is therefore expressed as (Eq. 5).

$$\sum_{i=1}^{n}(Y_i \times VWC_i \times X_i) \le \overline{W} \qquad \forall i \quad (5)$$

Finally, we define the following constraint (Eq. 6). for trade balance. Clearly, it states that the excess consumption of agricultural products is exported from the region and any shortage in internal use is provided through imports.

$$X_i \times Y_i - NM_i \ge C_i \qquad \forall i \quad (6)$$

Data on imports and exports, total production, land under cultivation and yields of products were obtained from the yearbooks of the Iranian Agricultural Ministry branch in Fars province. Other data including world prices of products and cost indices were taken from the World Bank publications. Furthermore, the domestic and relative prices of products and wages were obtained from publications of the Statistics Centre of Iran.

RESULTS AND DISCUSSION

The calculated amounts of virtual water are represented in Table 1. As shown, wheat and barley need less water as compared to other products, and tomato and sugar beet use less virtual water due to their high yields. The highest amount of virtual water is attributed to rice.

Considering the volume of virtual water used by these products, importing one kilogram of wheat, barley, rice, corn, tomato and sugar beet implies importing virtually 1.7, 2.9, 7.2, 3.7, 0.6 and 0.8 m^3 water, respectively.

* Crop Water Use

Comparing virtual water of the crops per kg sounds unfair due to disparity of their yields and values per hectare and so we calculated the virtual water per 1000 Rials values of the products. As shown in the fourth column of Table 1, the corresponding ratios vary between 0.2 and 2.8. Whilst the lowest amount of virtual water was attributed to tomato based on its yield, barley is recognized so through adjusting virtual water by total value products. The results of the products' social benefits have been shown in the last row of Table 1.

Table 1. Water used, virtual water, yield, virtual water to value of total product (VTP) and social profits of products in Marvdasht

	wheat	barley	rice	corn	tomato	sugar beet
Used water per hectare (m^3/ha)	9100	7605	32000	24000	34200	26000
Yield (kg/ha)	5336	2571	4434	6540	55767	33056
Virtual water (M^3/kg)	1.7	2.9	7.2	3.7	0.6	0.8
Virtual water to VTP (m^3 per 1000 Rials)	0.34	0.2	2.8	1.1	1	1.6
Net social profit per ha (million Rials)	10.3	-7.4	-25.4	-15.2	-35	-21.8

Based on the last row of the Table 1, only wheat has comparative advantage in production as shown by its net social profit of 10.3 million Rials per ha. The figures for other products are negative implying that they have social loss, the largest of which is related to tomatoes.

The optimal cropping pattern in the region can be recognized by a model that maximizes simultaneously both the social benefit and virtual water import. Model results are shown in Table 2. As can be seen, wheat and maize with land areas of almost 120 and 38 thousands ha, respectively, are the two products within the optimal cultivation model. The optimum land areas under cultivation of wheat and maize rise respectively by 90 and 230 percent, compared to the existing land areas and other products that are excluded from the cropping pattern. Moreover, social net profit per hectare is expected to sharply increase at the optimum cultivation pattern. The model also confirms the comparative advantage of wheat in the region.

Table 2. Results of different cultivation patterns in Marvdasht area (2007)

Patterns	Product							
	Wheat	barley	rice	corn	tomato	sugar beet	net social profit 10^6 Rials	net virtual water import 10^6 M^3
A bearable existing pattern (thousand ha)	63	5.2	32.5	115	4.7	2.6	611060	-1897
Maximum social benefit without adjustment factors (thousand ha)	119.6	0	0	38	0	0	654280	–934
Providing land to maintain current levels of employment (thousand ha)	98	0	0		32	0	-110600	–1705
Notwithstanding the increase of employment land (thousand ha)	114	0	0	0	28	0	194200	–1716
Land restricted fertilizers (thousand ha)	119. 6	0	0	1.8	0	0	1204520	-931
land bound to maintain the current employment, fertilizer and the current water restrictions (thousand ha)	766	0	294	0	105	0	-325280	–791

Source: research findings

In addition to optimal cropping pattern, net imports of the products are shown in Table 2. Accordingly, the optimization of land results in increasing the imports of net virtual water by 50%. In other words, rearranging agricultural exports from the region would prevent sending out 963 million cubic meters of water by utilizing the optimal land allocation.

As was discussed earlier, wheat and maize have fewer values in terms of virtual water in cubic meters per kg and also in cubic meters per 1000 Rials than other products.

In general, replacing products that require low water with those which need high water requirements is one of the options for improving the agricultural products. In other words, products with high water productivity should be replaced with low water productivity products to increase the water use efficiency and thus to obtain high economic value per unit of water and to save water for other essential domestic uses.

The results show that shadow price per one cubic meter of water is 828 Rials and water using between 1090259 and 3959000 cubic meters does not change the objective function. Despite the fact that the reduction of water through imports in low water circumstances is significantly reasonable by itself, it is coupled with some adverse effects such as reduction in employment.

The employment rates, measured by working persons per day (PPD), decreases nearly 434000 persons daily in current situation to almost 1821000 working persons per day (PPD), applying the optimum cultivation pattern. This reveals that producing high water requiring products also require more labor and switching to low water requiring products causes employment to be reduced as well. Therefore, determining land cultivation pattern based on virtual water should be accompanied with possible changes in employment in the region. Since the government policy is to keep the employment rates stable in the country as well as in the region, a cultivation pattern cannot be considered optimum if it causes some farmers to lose their jobs. Thus, the model is rerun in such a way that the current level of employment is kept unchanged.

Moreover, the optimum pattern results in a 40 percent increase in the consumption of fertilizers in the region creating environmental pollution and worsening the quality of groundwater.

Thus, lessening water consumption may raise various side effects and therefore it needs to be clearly justified such that the optimum pattern contains lower levels of water consumption while it keeps employment and prevents further consumption of fertilizer. The issue of maintaining employment level is considered below together with some further constraints in order to achieve a real optimal pattern for the region (Table 2).

Employment maintaining cropping pattern

The optimal cropping pattern that maximizes profit and social import of virtual water with limited employment in the regional level, shown in Table 2, includes only two crops, i.e. wheat and tomato with land under cultivation of 98 and 32 thousand hectares, respectively. This exhibits an increase in the lands of the two products by 55% and 580%, respectively. The reason behind the rapid inclusion of tomato in this pattern is due to labor intensive feature of this product. Although the pattern still shows net social loss, the corresponding figure decreases to -110.6 billion Rials that is significantly less than that of cropping pattern without limitation on employment.

Moreover, the net virtual water import of products specified in watershed area is shown in Table 2. According to the optimal cropping pattern, the net import of water increases to 1705 million cubic meters and 192 million cubic meters of water is expected to be added to regional water resources indicating a decrease of 742 million cubic meters compared to cropping pattern without employment restrictions.

Cropping pattern with employment increasing in the region

The results of the model with limited employment showed that employment between 1999995 and 3959091 working persons per day (PPD) will not change the objective function. Therefore, employment can be risen up by 117% from 1,821,437 to 3,959,050 persons, i.e. 3959050 further jobs per day, without any change in the value of objective function of the original optimum pattern. The respected findings of such increase in employment level are shown in Table 2. Implementing this plan causes the cultivated area of wheat and tomato to increase to 114 and 28 thousand hectares, respectively, indicating 81% and 496% growths compared to the existing lands of these two products. Again, cultivated lands of barley, rice, maize and sugar beet are zero. Social net profit per hectare of land is 194200 Rails at the optimum level.

According to the optimum cropping model, net import of water will rise to -1716 million cubic meters (mcm) and 181 million cubic meters of water may beaded to regional water resources. This is equivalent to 9% of water used in the region. Thus, for moderating the negative consequences of unemployment in the optimal cropping pattern based on virtual water, it is preferred to maintain the relative level of employment consideration along with the goal of maximizing virtual water import.

Limiting chemical fertilizer cropping pattern

The regional optimal cropping pattern that maximizes profit and social import of virtual water and constrains the chemical fertilizer use is shown in Table 3.

Under this model, the pattern includes wheat and maize with land areas of 119.6 and 38 thousand hectares, respectively, implying 90% increase of the former product and 84% decrease of the latter when compared with existing land areas of these two products. The social net profit per hectare of land reaches to 17742.2 billion Rails indicating 1158.8 billion Rails increase from that in the current pattern.

Net virtual water import of -1897 million cubic meters in the existing pattern reaches -93.1 million cubic meters and water exports from the region decreases by 966 million cubic meters.

The consumed inputs through the existing pattern, optimal cropping pattern and cultivation model with the **limit** of chemical fertilizer reduction are shown in Table 4.

As was discussed above, by taking into account one single objective, i.e. maximizing imported virtual water, would result in a pattern that can only satisfy the considered objective, while it is necessary to suggest a pattern that includes all the goals at the same time. In other words, the advantage of maximizing high virtual water imports should not lead to ignoring its corresponding costs. In this context, a pattern that takes all the goals into account is introduced in the next section.

By keeping the existent levels of employment, consumption of available fertilizers and water results in an optimal cropping pattern is shown in Table 4. At the optimal level, wheat, rice and tomato included in the model accounted for 76.6, 29.4 and 10.5 thousand hectares of available lands respectively revealing 22% and 123% increase of wheat and tomato cultivation areas and 10% decrease in land under cultivation of rice whilst the other products are excluded from the model†. The corresponding net virtual water import reaches -791 mcm that is 1105 mcm higher than that of the **original** optimal cropping pattern.

† Because the other products have less water use efficiency and social welfare.

As shown in Table 3, consumptions of inputs except labor and herbicides increase through this pattern.

Table 3. Total amount of inputs used in the existing cultivation model and the model maximizing social benefit

Description		The total consumption of inputs	Manufacturer maximum social benefit changes	Ratio changes to existing model(%)
Animal manure	tons	77 525	9862	-87
Herbicides	tons	275	313	13
Insecticide	tons	125	137	9
Fungicide	tons	97	65	-33
Phosphate fertilizer	tons	29736	36702	23
Urea fertilizer	tons	44887	66175	47
Potassium fertilizer	tons	1396	1938	38
Labor	(person days)	4339864	1821437	-58
Water consumption	Million cubic meter	2000	2000	0

Source: research findings

Table 4. Total amount of inputs used in the existing cultivation model and the model maximizing social benefit and model with the constraints of fertilizers

title		Total amount of inputs used in the existing cultivation model	Total used inputs in maximizing social benefit and model with the constraints of fertilizers	Ratio changes to existing model (%)
Animal manure	tons	77525	7082	-90
Herbicides	tons	275	147	-46
Insecticide	tons	125	106	-14
Fungicide	tons	97	64	-33
Phosphate fertilizer	tons	29736	30222	1.6
Urea fertilizer	tons	44887	44134	-1.6
Potassium fertilizer	tons	1396	1745	25
Labor	(person days)	4339864	872578	-79
Water consumption	Million cubic meter	2000	1133	-43

Source: research findings

CONCLUSIONS

Based on the findings of this study, it can be concluded that focusing on maximization of importing virtual water without regarding other vital issues including employment and available inputs forced us to cultivate a few crops such as wheat and corn that need less water. In order to create or to keep job opportunities, however, the cultivation patterns in a region should be determined such that maximizing imports of virtual water and social benefits is accompanied with introducing extra policies to guarantee that the current level of employment can be kept in the region. Based on the results, we recommend including wheat, rice and tomato at the cultivation pattern of the studied region as a pattern by which matter of virtual water is considered together with employment and optimum use of inputs at the same time.

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تعیین الگوی کشت محصولات کشاورزی با تاکید بر تجارب آب مجازی در منطقه مرودشت

محمد بخشوده، حامد دهقانپور*

بخش اقتصاد، دانشکده کشاورزی، دانشگاه شیراز، شیراز، ج. ا. ایران

*نویسنده مسئول

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مرودشت

چکیده- این مطالعه با هدف ارائه الگوی کشت بهینه بر اساس حداکثر واردات آب مجازی و سود خالص اجتماعی محصولات کشاورزی منتخب منطقه مرودشت شامل گندم، جو، برنج، ذرت، گوجه فرنگی و چغندر قند صورت گرفت. ابتدا الگوی بهینه کشت با محدودیت های آب و زمین ارائه گردید. در ادامه با توجه به اهمیت مصرف نهادها و اشتغال نیروی کار، الگوهایی تعدیلی به صورت حداکثرسازی تابع هدف مشروط به حفظ سطح فعلی اشتغال و یا قید افزایش اشتغال ارائه گردید. نتایج نشان داد که در منطقه مورد مطالعه تنها گندم دارای مزیت نسبی در تولید است و بیشترین زیان اجتماعی مربوط به گوجه فرنگی است. در الگوی کشت حداکثر کننده سود اجتماعی و وادرات آب مجازی مقید به سطح فعلی آب و زمین تنها دو محصول گندم و گوجه فرنگی انتخاب گردیدند. در مجموع مشخص شدمحصول گندم از نظر واردات بالای آب مجازی و همچنین گوجه فرنگی از نظر اشتغال بالای نیروی کار در مقایسه با سایر محصولات از اهمیت بالاتری برخوردارند با توجه به اهمیت اهداف ملحوظ در الگوهای تعدیلی بهتر است به تمامی ابعادالگوهای مبتنی بر حداکثرواردات آب مجازی توجه شود