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ORIGINAL ARTICLE

The Effects of Nutrition Patterns on Pistachio (*Pistacia vera* L.) Economic Yield in the Southeast of Iran

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K E Y W O R D S

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A B S T R A C T

Plant Nutrition management in its turn is affected by socioeconomic factors especially in a region with traditional fertilizing practices. Thus, it is required to analyze nutrition management in pistachio orchards socially and economically, especially in old areas such as Rafsanjan region. In the current study, these aspects were analyzed during five years. To this end, the population of pistachio producers in Anar and Rafsanjan cities was studied. Using the stratified random sampling method, a sample of the owners of 286 pistachio orchards was selected. Regression methods were used to measure the effects of different nutrition patterns on pistachio yield. Also, Logit model was used for measuring the effects of socioeconomic factors on the selection of nutrition patterns types. The results showed that among organic fertilizers, cattle manure was the most used in pistachio orchards this way chicken and sheep manures were in the second and third ranks, respectively. Investigation of NPK chemical fertilizers patterns showed that N was the most used and P and K are the second and third respectively. The results also showed that the use of micronutrient chemical fertilizers by pistachio producers has been increased during time. Our findings showed that manure and chemical fertilizers had positive effects on pistachio yield and were used less than the optimal economic level. The farmers' knowledge regarding nutrients usage and hope for the future were socioeconomic factors in selecting suitable nutrition patterns in their pistachio orchards. Therefore, enriching human and social capital can improve nutrition management in pistachio orchards.

Introduction

With respect to global food demand being doubled over the next 50 years, the food production, earth ecosystem, and social services will face significant challenges. Agricultural experts are managers of cultivable lands and may irreversibly shape the planet's surface in the future decades (Roointan *et al.*, 2018).

The most optimistic recent study shows that the world population will reach 9.7 billion in 2064. By 2065, the world's population will be up to 50% more than today, and global demand for food will be doubled due to the increase of 2.4 per capita income and a change in the taste of people for better food. Therefore, increased agricultural production is needed

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(Tilman *et al.*, 2002; Vollset *et al.*, 2020).

Regarding the above issues, achieving food security is one of the most important goals among various goals of the millennium (Pandey & Pandey, 2023). Achieving this important goal is only possible through increasing productivity. However, in developing countries, increasing productivity has its limitations. One of the most important restrictions in developing countries is the lack of nutrients for growing agricultural products. Nutrients, protein and oil content of the fruits is affected by climate and soil (Roozban *et al.*, 2006). The plant needs a certain amount of nutrients in a certain shape and right time to grow and develop. The role of both macronutrients and micronutrients are important in plant nutrition, and they are essential for a better yield. However, most soils are nutritionally poor and should be enhanced through appropriate nutrition management. Plant nutrients and nutrition management are possible through a variety of methods. These methods include the addition of manure and chemical fertilizers to soil, seed nutrition and nutrition through leaves. Each of these methods has its limitations and advantages (Ali *et al.*, 2008). Dessie *et al.* (2023) conducted a study in Ethiopia. This study was created to evaluate the Megech watershed's integrated smallholder soil fertility management methods' adoption factors, status, and scope A total of 380 individual farmers were surveyed using a semi-structured questionnaire to gather primary data. The research concluded that effective soil management policies and programs should be designed, and implemented by smallholder farmers, agricultural experts, research centers, and governmental and non-governmental organizations to improve soil quality for sustainable food production. Moreover, raising the affordability of financial services and strengthening smallholder farmers' access to education help to increase their income, which in turn encouraging the use of integrated soil fertility management practices.

In general, it can be said that various patterns of nutrition management are affected by various social and economic aspects and have different effects on product yield and economic return of production. Therefore, socioeconomic analysis of these patterns can play an essential role in nutrition management and agriculture.

Two other points emphasizing the importance of further socioeconomic studies on nutrition management are discussed in Goulding *et al.* (2008) They noted that lack of balance in using different elements due to different prices had led to the loss of many elements and economic loss. In addition, the export of food from developing countries to developed countries causes soil nutrient removal in some countries. Therefore, the real value of exports should be determined by economic studies of nutrition management.

Like other agricultural products, increasing pistachio yield per unit area is possible if the production factors are optimal and desirable. One of the weak aspects of management in the pistachio growing areas of the Iran is the management of nutrition and fertilization of orchards (Azarmi-Atajan and Sayyari-Zohan, 2022; Norozi *et al*., 2019). In Iran and pistachio growing areas, deficiency and imbalance of some nutrients in soil and leaf, and their negative effects on yield are visible (Heydari *et al*., 2025; Alipour, 2018; Esfandiarpour-Borujeni *et al.*, 2018; Hosseinifard *et al.*, 2010; Pourmohammadali *et al.*, 2019). Hence, the yield per hectare of Iran's pistachio orchards has decreased from 1200 kg to 400 kg (Iran's Agricultural statistics, different years).

Various socioeconomic studies have been done on soil nutrition management in agriculture. In the study conducted to determinants of soil fertility management practices in Gedeo Zone (*Southern Ethiopia*). The results showed that the socioeconomic status of farmers effected the adoption of soil fertility management practices (Mebrate *et al.*, 2022).

Van Den Bosch *et al.* (1998) examined the soil nutrients of the Sahara Desert in Africa. The results of this study indicated that family farms of this region had been faced with some changes in the price of agricultural products and agricultural inputs and thus had increased the pressure on the land This led to removing nutrients from the soil. Considering the socioeconomic conditions in the region, farmers had limited options for using appropriate nutrients or soil protection technologies. The study concluded that profitable and stable nutrition management required much more work than scattered activities. So, it was suggested that different fields join together and simultaneously examine the different dimensions of soil nutrients.

Beegle *et al.* (2000) showed that according to the traditional point of view, nutrition management is the maximization of the economic efficiency of using soil nutrients in the production of crops However, according to these authors, in addition to the technical and economic objectives of nutrition management, environmental impacts should also be considered. In other words, maximizing the economic benefits and minimizing the environmental impact of nutrition management should be considered simultaneously. In fact, the advanced nutrition management program should be based on a set of strategic goals agreed by farmers and the society. In addition, programs must be designed in a way to be applicable. Therefore, the complete and extensive participation of land owners, appropriate organizational structures, scientific nutrition management, voluntary and compulsory programs, and nutrition management should be considered.

Karimi *et al.* (2006) examined the effects of using different levels of N and P fertilizers on pistachio yield. The results of this study showed that the effect of using N on product weight, blank and non-splitting pistachio nuts was significant while using P did not affect pistachio yield and only affected blank nuts Tittonell et al. (2005) examined the changes in soil nutrition efficiency related to the farms in the family farms of Kenya. The results of the study showed that there were significant differences in the use of inputs among different fields. For example, application nitrogen varied from 0.7 to 104 kg ha^1. In addition, the results showed that farmers managed their farms based on their perception of soil quality. Inconsistency in resource allocation was also different for various socioeconomic groups which was due to the resource constraints. Socioeconomic factors were also influential in allocating resources to various activities. Therefore, these issues should be considered in soil nutrition management.

Salasya, Beatrice (2005) investigated the effects of socioeconomic factors on farms and decisions taken about nutrition management and production in the areas of Kiambo and Vihiga in Kenya. This research also studied the effect of these decisions on family goals and productivity. The results showed that the demand for non-organic fertilizers was high regarding the price In other words, in Kiambo, the price of product, especially cabbage, did not have much effect on fertilizers demand, because the effect of using fertilizers was low on the yield of these products. The findings also showed that labor was one of the limitations affecting the impact of non-organic fertilizers. In addition, the studied households used fertilizers lower than the optimal economic level. So, it was necessary to increase the amount of credits received by farmers in order to increase fertilizer use.

The results of a study by Ali *et al*. (2008) showed that all nutrition management activities had a positive effect on the product yield and suggested that integrated nutrition management should be applied. This integrated approach should be carried out at the farm level, and its economic impact should be considered. Acceptance of integrated nutrition management techniques can lead to more economical use of soil nutrients and their adaptation to the environment.

To the best of our knowledge, there has been no research on the socioeconomic study of nutrition in Iranian pistachio orchards. Only some case studies estimated the pistachio yield function and determined the optimal level of economic use of chemical and animal manures. For example, Mehrabi Bashrabadi (1995) identified the factors affecting pistachio yield and production in Rafsanjan and measured the productivity of the factors. Their results showed that some farmers had low productivity in using inputs such as labor, fertilizer in the economic study of pistachio production in Kerman province, it was found that the farmers of pistachio orchards over used the inputs such as animal manure, water and labor, and their use was for the third production area. Other important inputs that were in pistachio production were in the second production area Fatahi ardakani (1996) examined the productivity of factors affecting pistachio production in Ardakan. The results of this study showed that the productivity of production factors in the area was not high at the commercial level. Many farmers did not use inputs optimally, and if resources were reallocated, the yield could significantly increase. Farbood *et al*. (2006) examined the views of pistachio farmers about the pistachio yield. The results of this study showed that use of different amounts of animal manure and chemical fertilizer was not statistically significant regarding yield In addition, Sedaghat and Hosseinifard (2011) examined the role of orchard management on the quantitative and qualitative yield of pistachio. The results showed that proper management of pests and diseases, harvest, nutrition, irrigation and total soil quality of the farm had a positive effect on yield per hectare, while better management of production costs, high salinity and orchard area hurt yield. Roosta and Mohammadi (2013) indicated that manure, ammonium, and iron application could improve some nut quality factors in alkaline soils of Iranian pistachio orchards After studying pistachio orchards of Damghan, the north of Iran, Hojat and Ghorbani (2016) stated that 70 % of the changes of pistachio yield could be explained by animal manure, financial management, executive skills, soil texture and tree age

Sedaghat (2019) in a study aimed at investigating factors affecting pistachio orchards' productivity in Kerman province indicated that average productivity, maximum productivity and productivity growth rate had declined during study period (2012-2015). Results also indicated that producers' education level and chemical fertilizers amount had positive effect on total productivity, however, number of garden fractions, number of family members, ratio of the number of male to female tress and amount of organic manures had negatively affected on total productivity. Results also revealed that partial productivity of Labour force, fluid fertilizers, organic manures, and water resources positively affected on production per hectare. Finally, to enhance productivity and profitability of farming system and reach to a more sustainable one, it is suggested to provide necessary circumstances for entrance of agricultural graduated people in pistachio production sector, to program an integrate pistachio farms system and to put more effective supervision/monitoring on agricultural inputs and credits market.

Shahbazi Manshadi *et al.* (2022) with the aim of investigating the impact the effect of different levels of common fertilizers used in pistachio orchards on pistachio yield and quality characteristics, and optimization of chemical fertilizer. This research was accomplished at the Yazd University during 2018–2019. The results determined the optimum level of each fertilizer used for each variable (150 kg/ha Calcium nitrate for the total yield, 300 kg/ha triple superphosphate for the fruit ripening percentage, 150 kg/ha Calcium nitrate for the fruit split percentage, and 200 kg/ha urea for blankness). In the study by Seyed Mohammadi *et al.* (2023) with the aim of sustainable management of soil use and determining the most critical factors affecting pistachio yield, k-nearest neighbor, classification and regression tree algorithms and support vector machine algorithms were used. These methods explained the changes in pistachio yield with more than 80% accuracy. In this study, available soil phosphorus was the most critical factor determining pistachio yield, and soil salinity, percentage of exchangeable sodium, potassium, gypsum, calcium carbonate, and gravel were ranked in order of decreasing importance. These outputs can help planners and farmers to manage soil properties better to increase pistachio yield and sustainable production. In another study, exogenous calcium improved growth and physiological responses of pistachio rootstocks against excess boron under salinity (Mohit Rabari *et al.*, 2023).

As it was found out, none of the previous studies has shown different nutrition patterns, and the effect of integrated patterns on yield has not been studied. In addition, the impact of socioeconomic characteristics on the selection and use of these patterns has not been considered. Therefore, the current study aimed at considering these issues.

Materials and Methods

The data used in this study was prepared by a questionnaire delivered to farmers during 5 years. For this purpose, the sample was selected from the cities of Anar and Rafsanjan using stratified random sampling method. several samples were selected based on random sampling methods from the villages of these two cities. In the next step, a number of farmers were selected randomly from a list of farmers residing in sample villages. some farmers questioned was 100. Generally, among 100 farmers that were studied, 286 of their pistachio orchards were investigated.

In the present study, first, different patterns of nutrition management in the pistachio orchards were identified. In addition, the socioeconomic characteristics of the farmers and the orchards features were also questioned. Soil texture was determined based on the orchard owner’s point of view and the visit of the expert (Tittonell *et al*. 2005). Therefore, the farmers were asked to classify their orchard's texture into three groups: light, medium, and heavy. Water salinity was measured based on electrical conductivity (EC). In order to measure the annual amount of used irrigation water per hectare in the orchards, the farmers were asked the number and time of each irrigation frequency. Then, the wells discharge was measured. According to the existing conditions, it was measured by a triangle if the water was flowing through the tube. As water flowed through the channel, the discharge was measured using the floating object, average speed of water movement in the channel and calculation of the water cross-section in the channel. Finally, the annual use of water was calculated in m^3ha^{-1}.

In order to study the role of nutrition factors in pistachio yield, first the yield production function with independent structural variables was estimated (variables other than nutrition variables). These variables included water use, water salinity, soil texture, pistachio type, tree age, tree row, row spacing and trees distances in the row. This was done to homogenize conditions for the orchards to compare nutrition activities and their effect on yield. In addition, according to the available information, three separate regressions were estimated. In the regressions, the dependent variables were the average pistachio yield per hectare in the three periods of the study (2011-2013, 2014-2016 and 2011-2016). Moreover, the Logit model was used to investigate the effect of socioeconomic factors on choosing the type of management model (McFadden, 1973). Consequently, if a particular nutrition pattern was used, the dependent variable was 1; otherwise, it was 0. SPSS software package was used in this regard.

Results

Nutrition patterns

In Tables 1 to 3, the pattern of using fertilizers in two 3-year periods from 2011 to 2013 and from 2014 to 2016 is presented. Having two periods helped us to compare them. In addition, in these tables, the average of using these fertilizers in the pistachio orchards for 6 years is presented.

Table1. The amounts of using animal manure in pistachio orchards.

Manure type	2011 to 2013			2014 to 2016			2011 to 2016		
	ton ha^{-1} year^{-1}								
	min	max	average	min	max	average	min	max	average
Cattle	0.00	72.00	10.52	0.00	40.00	11.29	0.00	51.00	10.92
Sheep	0.00	26.67	2.72	0.00	24.00	3.93	0.00	21.34	3.39
Chicken	0.00	34.00	7.21	0.00	80.00	8.39	0.00	51.00	7.82
All 3 types of manure	0.00	74.00	20.53	0.00	94.66	23.83	0.00	69.33	22.38

As shown in Table 1, cattle manure had the highest use among the three types of animal manure in these orchards. The average annual use of this manure was about 11 ton ha^{-1}. Of course, this did not mean that every year this amount of cattle manure was used in all the pistachio orchards. However, it might take 22 tons in a year, and in the following years its use decreased to zero. This also applied to the other two types of manure. The second most commonly used manure in the pistachio orchards was chicken manure, and sheep manure was in the third place. Based on the results of Table 1, in the 6-year period, nearly 49% of animal manure used in the pistachio orchards was cattle manure. Chicken manure use was 35% and sheep manure was only 16%. The amount of using these three types of animal manure did not change significantly over time, and their use remained approximately the same. The application of manure increases soil productivity as it improves soil physical, chemical and biological properties. Soil organic matter may promote crop yields through supplying multiple nutrients, encouraging microbial activity and improving infiltration rate (He, 2020; Sanden *et al.*, 2005; Swift, 2001).

As Table 2 shows, in the 3-year and 6-year periods, N fertilizer had the highest use in the pistachio orchards among the three macro-fertilizers. P and K fertilizers were in the second and third priority, respectively. The amount of K fertilizer use remained relatively constant over the first 3-year compared to that in the first period. However, P and N fertilizers use decreased.

Table 2. The amounts of using chemical macronutrient fertilizers in pistachio orchards.

Chemical fertilizer type	2011 to 2013			2014 to 2016			2011 to 2016		
	kg ha^{-1}								
	min	max	average	min	max	average	min	max	average
P	0.00	1200	184	0.00	1400	152	0.00	1300	169
K	0.00	1400	95	0.00	800	93	0.00	1100	97
N	0.00	1000	259	0.00	800	209	0.00	900	236
Sum of three fertilizers	0.00	2800	532	0.00	2000	459	0.00	2400	502

As Table 3 shows, although the use of gypsum in the studied pistachio orchards was generally low, in the second period (2014- 2016), the amount of gypsum used was higher than that in the first period (2011-2013). The use of aeolian sand in the orchards was extensive while, in the 3-year period, aeolian sand was ordinary in 70% of these orchards and reached 90% in the 6-year period. About 80% of the pistachio orchards used micro-fertilizers for at least one period a year. Spraying was used in more than half of these orchards. In 30% of the studied pistachio orchards, the triple micronutrient fertilizer (iron, zinc, and manganese) was sprayed. zinc spraying in the first period in 20% of these orchards nearly doubled in the second period. This suggested that zinc spraying was increasing.

Another fertilizer that increased in the pistachio orchards was calcium fertilizer so that the percentage of the orchards in which calcium spraying was used in the second period increased nearly five times in comparison to that in the first period. The increase of calcium spraying and gypsum use showed that calcium increased in these orchards.

Table 3. Pistachio orchards percentage using chemical micronutrient fertilizers and reclamation materials.

Used materials and practices	2011 to 2013	2014 to 2016	2011 to 2016
	Pistachio orchards percentage		
Gypsum	6	16	16
Aeolian sand	74	69	86
Micronutrient fertilizers	63	68	81
Spraying of fertilizers	59	72	79
Spraying of triple elements (Fe, Zn, Mn) fertilizers	28	27	47
Spraying of Zn-fertilizer	20	36	47
Spraying of Ca-fertilizer	4	19	25

Effects of nutrition patterns on pistachio yield and their economic evaluation

The results of studying the role of nutrition factors in pistachio yield are presented in Table 4. In this table, only those independent variables appear that were significant with t value less than 10%. The first power of water volume in all three regressions was significant. However, the second power variation of water volume in each of the three regressions was not significant. This indicated that the number of the pistachio orchards with a high water use (in the third production area) was low in the sample, which made it impossible to estimate water production function thoroughly. Nevertheless, as the estimation of the first power was sufficient, the variation of irrigation water volume in the pistachio orchards was essentially eliminated. The coefficient of the first power of water volume variable for the three years of 2011 to 2013 was 0.064, less than the coefficient for the 3 years of 2014 to 2016 (0.08). This coefficient represented the marginal product (MP) of 1m^3 of water.

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Table 4. Regression of pistachio yield (kg ha^{-1}) with independent structural variables.

Variable	2011 to 2013			2014 to 2016			2011 to 2016		
	Estimated coefficient	**t**	**Significant level**	**Estimated coefficient**	**t**	**Significant level**	**Estimated coefficient**	**t**	**Significant level**
Constant value	147.05	0.66	0.51	325.61	1.29	0.2	54.53	0.25	0.80
Irrigation water volume (m^3 ha^{-1})	0.064	5.48	0.00	0.080	6.23	0.00	0.076	6.60	0.00
ECw (µmho cm^{-1})	0.154	2.65	0.01	0.108	1.67	0.10	0.160	2.68	0.01
Second power of ECw	0.000009-	-2.94	0.00	-0.000008	-2.21	0.03	-0.000001	-3.08	0.00
Soil texture (clay=1, others=0)	-325.74	-2.25	0.02	-310.4	-2.03	0.04	-355.37	-2.57	0.01
kaleghochi=1) Pistachio cultivar Others=0)	-267.85	-2.21	0.03	-	-	-	-	-	-
Pistachio cultivar Ahmadaghaei=1) Others=0)	-	-	-	507.22	3.16	0.00	338.03	2.34	0.02
R^2	0.19			0.24			0.23		
adj R^2	0.17			0.23			0.22		
F	11.42			14.88			1.386		
sigF	0.00			0.00			0.00		

In other words, the MP of 1 m^3 of water was 64 g for the 3 years of 2011to 2013, and it increased to 80 g for the 3 years of 2014 to 2016. The MP of water volume in the 6-year period was between these two periods was 76 g m^{3}.

Another variable that had a significant effect on the yield in all the three regressions was EC of water (Table 4). The higher the value of this variable, the lower the quality of used water. The first and second powers of EC variables were significant in all the three regressions. The first power was positive and the second was negative indicating that increasing EC to some extent increased pistachio yield but more increase in EC lead to a decrease in the product. According to the coefficients of Table 4, and the derivation of EC, the optimal value of this variable was 8555, 6750, and 8000 µmhocm^{-1} in the first and second 3-year periods and 6-year period, respectively. In other words, the optimum salinity was in the range of 6500 to 8500 µ mho/ cm^{-1}. This meant that water with an EC of less than 6500 and more than 8500 caused a decrease in the yield. EC variable in the regression equations also made the pistachio orchards under study to be homogenized in terms of water quality.

Another variable, which was significant in three regressions was soil texture (Table 4). Based on the collected data, the studied soil texture was divided into three light, heavy, and medium groups. For entering soil texture into the regression, the dummy variables were used. For example, a variable called heavy soil texture was defined. If the soil texture of the studied orchards was heavy, this variable was set to 1, and if it was light or medium, it was considered 0. Similarly, the two variables of medium and light soil texture were also defined. Among the three variables, the heavy soil texture had the best significant level. Thus, this variable entered the regression. The coefficient of the dummy variable of heavy soil texture was negative and about -300 in the first, second and 6-year periods. In fact, averagely, heavy textured soils had less yield (300 kg ha^{-1}) than light and medium soil textures. Hosseinifard *et al*. (2005) stated that heavy soil texture is one of the limiting factors for pistachio trees growth in Anar region. In the presence of soil texture variables in the regression, the pistachio orchards also became similar in soil texture.

The fourth independent variable in Table 4 is thr pistachio cultivar. In the first 3 years, the dummy variables of the Kaleghochi cultivar had a significant and negative effect. It could be said that pistachio orchards of Kaleghochi had a lower yield of 268 kg ha^{-1} than Ohadi, Akbari and Ahmadaghaei cultivars. In the second 3 years, the variable of Kalehghochi was not significant, but that of Ahmadaghaee with a positive coefficient was significant. This indicated that during the first period and when rainfall was much lower, Kalehghochi yield decreased, during the second 3-year period, with an increase in rainfall, Kalehghoochi yield was in line with the average yield of the other types. However, in the present study, the presence of pistachio variables was homogenized in different cultivars of pistachio.

Except for the four variables in Table 4, other structural variables were insignificant in the regression. These variables included tree age, row order, row spacing, and etc. This indicated that the studied pistachio orchards were homogeneous for these variables, with no significant difference between them. Therefore, with four variables such as water quantity, water EC, soil texture, and pistachio cultivar in the regression, it could be said that the studied pistachio orchards were homogenized and the differences among pistachio yields and these orchards were due to management factors. In the present study, only nutrition management factors were studied. Therefore, each management variables was separately entered into the regression of Table 4, and its effect on pistachio yield was measured. In other words, there was always only one nutrition management variable in the regression as most of variables had a strong correlation, and their simultaneous attendance made regression errors. In the following, the tables for various nutrition variables are presented. Here, only the variables are presented whose t was significantly less than 10%.

As Table 5 shows, in the regression of the 3-year period of 2011 to 2013, the first power of cattle manure use was significant, but the amount of cattle manure was not significant in the other two regressions. The value of the variable coefficient of cattle manure used in the yield regression of the first 3 years was 10.26. This indicates that 10.26 kg of pistachio will be produced if a ton of cattle manure is used in pistachio orchards. This number represents the marginal product of the cattle manure. If this number is multiplied by the average price of pistachio (10 USD kg^{-1}), 102.6 USD is obtained. In other words, if the cost of buying one ton of manure is less than 102.6, using more than the current amount of cattle manure (average 10.53 tons ha^{-1} $year^{-1}$ according to Table 1) will be economical. Since the current price of cattle manure in the market is less than 20 USD, it can be said that using more than 10.52 tons ha^{-1} $year^{-1}$ of this manure is economical. Meek *et al*. (1982) reported more than doubled infiltration rates in a clay soil with about 10 $tonha^{-1}$ dairy manure. Since, according to available data, the second power of cattle manure in the regression model was not significant, it was not possible to measure the optimum economic value of cattle manure in the pistachio orchards.

The first and second powers of chicken manure use was significant for the first 3-year and 6-year yield regressions (Table 5). Calculations showed that the marginal products of one ton of chicken manure in the first 3-year and 6-year periods were 41.74 and 25.92 kg of pistachio, respectively. Comparing these numbers with the final production of cattle manure showed that chicken manure had a higher marginal product than cattle manure. Some of these differences were because chicken manure was used less than cattle manure.

If the amount of chicken manure is equal to the amount of cattle manure, (10.52), its marginal product for the first 3-year and 6-year periods will be 32.87 and 18.88 kg of pistachio per ton of chicken manure, respectively. These numbers indicated that the marginal products of chicken manure in the first 3 and 6-year periods were three and two times more than those of cattle manure, respectively. However, the effect of chicken manure decreases in long-term use. Some studies have shown that the application of poultry manure increases fertility and nutrient availability in soil (Liu *et al.*, 2016; Sadegh *et al.*, 2012)

Table 5. Regression coefficients of the effect of animal manure use on pistachio yield (kg ha^{-1}).

variables	2011 to 2013	2014 to 2016	2011 to 2016
	variables coefficient		
The first power of cattle manure use in 2011-2013 (ton $ha^{-1}year^{-1}$)	10.26	-	-
The first power of chicken manure use in 2011-2013 (ton $ha^{-1}year^{-1}$)	61.06	-	46.57
The second power of chicken manure use in 2011-2013 (ton $ha^{-1}year^{-1}$)	-1.34	-	-1.32
The first power of chicken manure use in 2014-2016 (ton $ha^{-1}year^{-1}$)	-	-	34.96
The second power of chicken manure use in 2014-2016 (ton $ha^{-1}year^{-1}$)	-	-	-0.37
The first power of sheep manure use in 2014-2016 (ton $ha^{-1}year^{-1}$)- EC water <8000	-	-	52.40
The second power of sheep manure use in 2014-2016 (ton $ha^{-1}year^{-1}$)- EC water <8000	-	-	-4.07
The first power of chicken manure use in 2011-2016 (ton $ha^{-1}year^{-1}$)	-	-	45.74
The second power of chicken manure use in 2011-2016 (ton $ha^{-1}year^{-1}$)	-	-	-0.73
The first power of sheep manure use in 2011-2016 (ton $ha^{-1}year^{-1}$)- EC water <8000	-	94.07	-
The second power of sheep manure use in 2011-2016 (ton $ha^{-1}year^{-1}$)- EC water <8000	-	-9.10	-
The first power of 3 animal manure use in 2011-2013 (ton $ha^{-1}year^{-1}$)	15.84	-	9.89
The first power of 3 animal manure use in 2014-2016 (ton $ha^{-1}year^{-1}$)	-	-	6.58
The first power of 3 animal manure use in 2011-2016 (ton $ha^{-1}year^{-1}$)	-	-	12.67

According to Table 5, the marginal products of chicken manure in the first 3-year and 6-year periods in the 6-year yield regression were 12.47 and 34.32 kg of pistachio per ton of chicken manure, respectively. Comparing these numbers with the previous calculations showed that the highest marginal product of chicken manure was due to the effect of using the first 3-year chicken manure on its yield. The effect of the average 6-year use on its yield was in the second place. Meanwhile, the effect of chicken manure use in the first 3-year period on the 6-year yield average was in the third place. The fourth place was the effect of using chicken manure in the second 3-year on the average of the 6-year yield. The low place of the fourth was because chicken manure use in the second 3 years did not effect the first 3-years yield, and this led to its small effect on the average of the 6-year yield. However, the overall conclusion about the marginal product of chicken manure was that the effect of long-term use of this manure on yield significantly decreased. This finding corresponds with the chemical properties of chicken manure because chicken manure has highly soluble minerals and does not need to decompose to affect soil. In other words, nutrients in chicken manure are available for the plant in short-term.

Since in all the periods the second power of chicken manure use was significant, it is possible to calculate the optimum amount of this manure use in pistachio orchards. This optimum amount is calculated by having the price of one kg of pistachio and the price of chicken manure per ton and equalizing the marginal product of chicken manure with its price per ton. The calculated amounts are as follows (the price of one kg pistachio is 10 USD and the price the one ton of chicken manure is 20 USD):

– Optimum use of chicken manure in the first 3-year period in the first 3-year yield regression: 19.20 ton ha^{-1} $year^{-1}$

– Optimum use of chicken manure in the first 3-year period in the 6-year yield regression: 14 ton ha^{-1} $year^{-1}$

– Optimum use of chicken manure in the second 3-year period in the 6-year regression: 9.46 ton ha^{-1} $year^{-1}$

– Optimum use of chicken manure in the 6-year period in the 6-year regression: 24.75 ton $ha^{-1}year^{-1}$

Considering the optimum calculated amounts and comparing them with the current amounts of chicken manure used in the pistachio orchards (Table 1), it is clear that the optimum economic amount is higher than the current amounts. In other words, in the studied pistachio orchards, from the economic point of view, more amounts of chicken manure should be used. Due to water shortage and high irrigation frequency, salinity of water and soil, and high soluble minerals of chicken manure, it is scientifically necessary to use it precisely.

The first and second powers of sheep manure use were significant in the second 3-year yield and 6-year regression (Table 5). The manure was used when the water EC was less than 8,000 µmho cm^{-1} and affected pistachio yield. The calculations showed that the marginal product of used sheep manure in the 6-year period in the second 3-year yield regression was 32.37 kg per ton of sheep manure, and this in the second 3-year period in the 6-year yield regression was 20.42.

Because the price of one kg of pistachio is10 USD kg^{-1}, and the price per ton of sheep manure is19 USD, the optimum economic amount of sheep manure is as follows:

- The optimum amount of used sheep manure in the second 3-year period in the 6-year yield regression: 5.55 ton $ha^{-1}year^{-1}$.

- The optimum use of sheep manure in the 6-year period in the second 3-year yield regression: 4.77 ton ha^{-1} $year^{-1}$.

As it is clear, with the current price of sheep manure and pistachio, and the EC of water less than 8000 µmho cm^{-1}, the optimum amount of used sheep manure was 5 tonha^{-1} $year^{-1}$. This amount is about 1 ton more than the currently used manure in the pistachio orchards. Tekin *et al*. (1995) showed that 60 kg per tree of sheep manure significantly increased pistachio yield.

The total amount of using three types of animal manure (chicken, sheep, and cattle) was significant in the first 3-year and 6-year regressions. In all the periods, only the first power of the variable was significant. Therefore, the optimum economic amount of all three types of used manure could not be calculated. However, the marginal product of the three types of animal manure in the first 3-year in the first 3-year yield regression was 15.88 kg of pistachio per ton of animal manure. In addition, the average annual use of the three types of animal manure in the 6-year period for the average yield of the 6-year period had a marginal product of 12.67 kg of pistachio per ton of manure. As the use of animal manure in the second 3-year period did not affect the yield of first 3-year, the coefficient of this variable could not be interpreted correctly in the 6-year regression. Thus, the marginal product of total animal manure should be calculated based on the two amounts of 15.88 or 12.67. Here, 12.67 was used because it contained the long 6-year period. So, it can be said that the marginal product of using one ton of the three manure types of cattle, chicken, and sheep was 12.67 kg of pistachio. Assuming that the three types of manure are used equally, the price of one-ton mixture of the three types will be 20 USD. If 12.67 is multiplied by pistachio price (10 USD kg^{-1}), the value of the marginal product of one-ton mixture of the three types of animal manure will be 126.7 USD. The optimum amount of using the mixture of the three types of animal manure was more than the then used amount (22.38-ton ha^{-1} $year^{-1}$) in the studied orchards. Generally, it can be said that farmers should increase the amount of these three types of manure averagely. Masto *et al*. (2007) showed that the quality index rating was the highest for manure-treated soils Kumar *et al*. (2022) indicate that the manure application not only reduces the need for a higher amount of mineral N fertilizer but also improves the soil physicochemical and biological properties with direct effects on crop yield.

Table 6 shows the regression coefficients of the effect of nitrogen, potassium, and phosphate fertilizers on pistachio yield (kg ha^{-1}) in the studied orchards.

Table 6. Regression coefficients of the effect of macronutrient fertilizers use on pistachio yield (kg ha^{-1}).

variables	2011 to 2013	2014 to 2016	2011 to 2016
	variables coefficient		
The first power of N fertilizer use in 2011-2013 ($kgha^{-1}year^{-1}$)	-	1.74	1.34
The second power of N fertilizer use in 2011-2013 ($kgha^{-1}year^{-1}$)	-	-0.002	-0.002
The first power of K fertilizer use in 2011-2013 ($kgha^{-1}year^{-1}$)	1.77	1.34	1.46
The second power of K fertilizer use in 2011-2013 ($kgha^{-1}year^{-1}$)	-0.001	-0.001	-0.001
The first power of P fertilizer use in 2014-2016 ($kgha^{-1}year^{-1}$)	-	2.37	-
The second power of P fertilizer use in 2014-2016 ($kgha^{-1}year^{-1}$)	-	-0.006	-

The first and second powers of N fertilizer use in the first 3-year period in the second 3-year and 6-year yield regressions were significant. The calculations showed that the marginal product of N fertilizer used in the first 3-year period in the second 3-year and 6-year yield regressions were 0.70 and 0.30 kg pistachios per kg of N fertilizer. Regarding the fact that the price per kg of pistachio is 10 USD and the price of N fertilizer is 0.1 USD per kg, the optimal economic amount of used N fertilizer is measured as follows:

- The optimum amount of N fertilizer in the first 3-year period in the second 3-year yield regression: 425 kg ha^{-1} $year^{-1}$.

- The optimum amount of N fertilizer in the first 3-year period in the second 6-year yield regression:

325 kg ha^{-1} $year^{-1}$.

Since N fertilizer causes more vegetative growth of trees, this growth causes more flower buds to grow in the future and the products will increase in the following years while it has lower effect on the yield of the current year. Nitrogen-deficient trees in soil are trying to use more of their existing nitrogen, and despite yellow leaves and the tree's weakness in the current year, it yields fruit but will be in trouble for the next year. This led the marginal product of N fertilizer used in the first 3-year period in the second 3-year regression to be more than that of the 6-year regression. Regarding this issue, considering the marginal product of N fertilizer used in the first 3-year period looks more realistic for the second 6-year regression. Accordingly, the optimal economic use of N fertilizer was calculated at 325 kg $ha^{-1}year^{-1}$. The comparison of the actual amount of N fertilizer used in the studied pistachio orchards (259 kg ha^{-1} $year^{-1}$, according to Table 2) showed that the optimum amount of used N fertilizer was higher than the average of used N fertilizer in these orchards.

As shown in Table 6, the first and second powers of K fertilizer use in the first 3-year period were significant in the first, second, and 6-year yield regressions. Marginal products of used K fertilizer in the first 3-year period in the first, second, and 6-year yield regressions were 1.85, 1.15, and 1.27 kg pistachios per kg of used K fertilizer, respectively. The price of one kg of pistachio is 10 USD and one kg of K fertilizer is 0.33 USD, so the optimum amount of used K fertilizer is calculated as follows:

- The optimum amount of K fertilizer used in the first 3-year period in the first 3-year yield regression: 819 kg $ha^{-1}year^{-1}$

- The optimum amount of K fertilizer used in the first 3-year period in the second 3-year yield regression: 604 kg ha^{-1} $year^{-1}$

-The optimum amount of K fertilizer used in the first 3-year period in the 6-year yield regression: 664 kg $ha^{-1}year^{-1}$

clearly, the optimum economic amount of K fertilizer used in the 6-year regression period was 664 kg ha^{-1}. This amount was seven times more than the amount consumed (95 kg ha^{-1} $year^{-1}$). In other words, K fertilizer used in pistachio orchards is very low. the K fertilizers are used during winter and summer in these orchards, and their use is not limited by water quality and air temperature. They also have a positive effect on the vegetative growth of pistachio plants and affect the weight and quality of the product of the current year. As it is known, potassium fertilizer was more effective than N fertilizer in the whole period. These factors led to an increase in the marginal product of K fertilizers in the pistachio orchards, and thus, the optimum economic value of this fertilizer was measured high.

The first and second powers of used P fertilizer were significant in the second 3-year period in the second 3-year yield regression (Table 6). The marginal product of P fertilizer used in the second 3-year period in the second 3-year yield regression was 0.55 kg of pistachio per kg of P fertilizer. Considering that the price of one kg of pistachio is 10 USD and the price per kg of P fertilizer is 0.1 USD per kg, the optimal economic value of P fertilizer is calculated as follows:

- Optimum use of P fertilizer in the second 3-year period in the second 3-year yield regression: 194 kg ha^{-1} $year^{-1}$.

Comparing the optimum economic amount of used P fertilizer (194 kg $ha^{-1}year^{-1}$) with its then used amount (169 kg ha^{-1} $year^{-1}$, according to Table 2) shows that P fertilizer use was economical.

Table 7 shows the effect of using micro-fertilizers on pistachio yield. The amounts of using these fertilizers were not specified, so there was no possibility to determine their optimal amounts. All the numbers in this table are in the range of 300. In other words, the use of micro-fertilizers (spray or soil) had an average yield of 300 kg $ha^{-1}year^{-1}$. This meant those farmers who used some kinds of micro-fertilizers, compared to the farmers who did not use them, had an average yield of 300 kg ha^{-1} of pistachio more. The second point is that among different micro-fertilizers used, spraying the triple micro-fertilizer (iron, zinc, and manganese) was more effective than other micro-fertilizers. The third point is that according to the price of 10 USD per kg of pistachio, the marginal product of micro-fertilizers in the pistachio orchards was 3000 USD ha^{-1} year^{-1}. The cost of three times spraying was approximately 150 USD ha^{-1} year^{-1}, which was much lower than the value of the marginal product of this input. As found by Pourmohammadali *et al*. (2020), leaf Fe and Cu are among the most essential features affecting pistachio yield in Rafsanjan region

Table 7. Regression coefficients of effect of micronutrient fertilizers used on pistachio yield (kg ha^{-1}).

variables	2011 to 2013	2014 to 2016	2011 to 2016
	Variables coefficient		
Fertilizers spraying in 2011-2013	294.11	-	-
Using micronutrient fertilizers in 2011-2013	277.08	-	-
Spraying triple micro-fertilizer* in 2011-2013	375.88	-	-
Using triple micronutrient fertilizers in 2011-2013	384.98	-	-
Using micronutrient fertilizers in 2014-2016	-	388.51	305.93
Triple micronutrient fertilizers spraying in 2014-2016	-	-	294.64
Using triple micronutrient fertilizers in 2014-2016	-	-	373.71
Using micronutrient fertilizers in 2011-2016	-	286.11	283.92
Using triple micronutrient fertilizers in 2011-2016	-	313.96	408.61
Spraying triple micronutrient fertilizers in 2011-2016	-	-	275.13

* triple micronutrient fertilizer: a liquid micronutrient fertilizer with three elements including Fe, Zn and Mn.

The portion of the three groups of nutrition factors and irrigation water volume in the pistachio yield are presented in table 8. In this table, it is assumed that other management factors (including pests, diseases, etc.) are equal in the studied orchards that have an average level. In this table, it is assumed that other management factors (including pests, diseases, etc.) are equal in the studied orchards that have an average level. In this table, it is assumed that other management factors (including pests, diseases, etc.) are equal in the studied orchards that have an average level. In this table, it is assumed that other management factors (including pests, diseases, etc.) are equal in the studied orchards that have an average level. The irrigation water volume input alone included 40% of the yield. In other words, in terms of supplying other management factors without using nutrition elements and with the assumption of supplying an adequate water (average of 9731 m^3 ha^{-1} year^{-1}), the yield per hectare will be 623 kg ha^{-1}. Pourmohammadali *et al*. (2019) studied pistachio orchards of the Rafsanjan region and indicated that the amount of consumed water, with a significant coefficient of 17.40%, was the most determinant parameter influencing pistachio yield. If animal manure is added, it can add 19% to the yield of pistachio orchards, and the yield is increased to 906 kg ha^{-1}. If using animal manure, the addition of macro-fertilizers can increase the yield by about 19%, up to 1193 kg ha^{-1}. Then, if micro-fertilizers are added, 20% will be added to the yield reaching 1493 kg ha^{-1}. Of course, the interactions of these inputs should not be ignored.

Numbers in Table 8 cannot be assumed to be unambiguous and comprehensive. Depending on different conditions, these numbers will vary. Nevertheless, these numbers represent the position of each of the three groups of nutrition inputs and their comparison with irrigation water volume. Farmers can compare their conditions with this table and determine the best way to achieve higher yields.

Table 8. Portion of irrigation water volume and different nutrition factors in yield.

Input	Input marginal product (kg pistachio/used input unit)	Used input average (input unit/ha)	Produced pistachio yield by input (kg ha^{-1})	Input portion of total yield (%)
Irrigation water volume (m^3 ha^{-1})	0.064	9731	623	41.73
Sum of animal manure (ton $ha^{-1}year^{-1}$)	12.67	22.38	283	18.95
Sum of used macronutrient fertilizers (kg ha^{-1})	0.55	502	287	19.22
Micronutrient fertilizers (use or non-use)	1	300	300	20.10

Social evaluation

Three Logit models were estimated for studying the effect of social factors on selecting the type of nutrition management. The use or non-use of cattle manure, P fertilizer and micro-fertilizer was considered an indicator of three nutrition patterns of animal manure, macro and micro-chemical fertilizers, respectively. If the desired fertilizer was used, the dependent variable was 1, and if it was not used; then it was 0. The results are presented in Table 9.

The statistics presented in the table also show the good fit of the model. Three variables of farmer's general literacy, professional agricultural knowledge about nutrition in pistachio orchards and the hope for the future survival of pistachio orchards in the region were effective in the nutrition pattern used by the farmers. The farmers' general education included their formal education level. Their specialized knowledge was measured based on 59 different types of nutrition indicators that were used for feeding pistachio orchards. Therefore, for each index the score was 20, so the total score of nutrition knowledge was 1180. The desire to migrate was an indicator of the future of the studied orchards.

The farmers, who were completely disappointed with the future of the water resources in the region, considered migration to other parts of the country as the only way to save themselves. However, the hopeful farmers believed in the improvement of irrigation methods, the conservation of existing water resources, and the transfer of water to the region as appropriate solutions for the water crisis in the region.

Regarding the three independent variables in Table 9, it can be said that increasing the general literacy level of farmers decreased the probability of using cattle manure and increased the probability of using macro and micro-fertilizers. This increased probability for micro-fertilizers was higher than that for macro-fertilizers. However, increasing farmers' knowledge about nutrition in the pistachio orchards increased the probability of using all three types of fertilizers. In this regard, the probability of increasing using micro-fertilizers was the highest one, and macro-chemical fertilizers were the second and third priority. Therefore, it should be noted that increasing the level of general knowledge of farmers does not guarantee an increase in the productivity of using agricultural inputs, especially nutrition inputs, and may have adverse effects. Instead, farmers' special knowledge of using inputs should be taken into consideration.

As Table 9 shows, to be disappointed with the future of water resources makes it possible to decrease the probability of using all three manure groups. In this regard, a decrease in the probability of using cattle manure was more than that in the two groups of chemical fertilizers. It is due to the timetaking efficiency of animal manure and its high cost In other words, despair about the future of water resources forces the farmer to use water and soil resources with short-term planning.

Table 9. Estimated coefficient regression of social factors affecting choosing different nutrition patterns in pistachio orchards

variable	Estimated coefficient regression of social factors affecting:		
	Cattle manure use	P fertilizer use	Micro-fertilizer use
Constant	1.34	-0.155	-0.67
Farmer literacy (education year)	-0.102	0.055	0.104
Belief in migration as a water problem solution (yes=1, no=0)	-3.02	-1.25	-1.47
Farmer's score for nutrition knowledge (from 1180)	0.004	0.003	0.006
-2log likelihood	318.31	352.81	320.20
Cox & Snell R^2	0.11	0.073	0.16
Nagelkerke R^2	0.16	0.10	0.27
Chi-squer	81.89	21.50	61.00
Chi-squer Sig	0.00	0.00	0.00

This will lead to complete and rapid destruction of water and soil resources. Therefore, if appropriate solutions to solve the water shortage are not offered, it will be better not to disappoint farmers towards the future which would increase the destruction of these resources. Feeling, feeling limited is better than a sense of frustration. The appropriate option is to inform farmers in a correctly and suitably way so that they know water resources are not unlimited, but they should be careful about their use.

Discussion

In pistachio growing areas of Kerman in Iran, investigating the pattern of using organic fertilizers showed that in pistachio orchards, cattle manure was the most used one, and chicken and sheep manure were the second and third priority, respectively. The criteria determining this organic fertilizer pattern in pistachio orchards included fertilizer price, water and soil salinity, and fertilizer content. It was found that in the time of study, the farmers used cattle manure less than the economic level. Also, the application of chicken manure in the pistachio orchards had a higher marginal product than that of cattle manure. The marginal product of sheep manure was positive when the EC of used water was less than 8000 µmho/cm^{-1}, and sheep manure did not have such efficiency in saline and low-quality water.

Among three fertilizers of nitrogen, phosphate and potassium, the highest use was related to N fertilizer, and P and K fertilizers were in the second and third priority, respectively. The use of these three fertilizers was less than the economic amount, and an increase in their use is justified from the economic point of view. The optimal economic value of using all the three types of macro-fertilizers indicated that the amount of K fertilizers should be increased more than the other two types.

The use of micro-chemical fertilizers and gypsum increased over time. Pistachio orchards that used micro-fertilizers had an average of 20% more yield than those orchards not using these fertilizers. The percentage of the pistachio orchards in which calcium spraying was done increased five times during the study period.

Investigating the role of effective socioeconomic factors on the selection of nutrition patterns for pistachio producers showed that increasing the level of general literacy of the farmers decreased the probability of using cattle manure and increased the probability of using macro- and micro-fertilizers. This increased probability for micro-fertilizers was more than macro- fertilizers. However, increasing the knowledge of the farmers about nutrition in the pistachio orchards increased the probability of using all the three groups of fertilizers. Since increasing the general knowledge level of farmers does not guarantee an increase in the efficiency of using agricultural inputs, and specially nutrition inputs, it is necessary to pay more attention to increasing farmers' specialized knowledge about using inputs.

Disappointment with the future of water resources will make the farmer try to use the resources of water and soil in the short term. This will lead to the complete and rapid degradation of water and soil resources. Thus, an appropriate option is to inform farmers correctly so they feel water resources are not unlimited, but they should be careful about their use. However, they should not be completely disappointed with these sources and find no way to improve the situation.

The findings of this research demonstrated that different nutrition patterns significantly affect the economic yield of pistachio production in Anar and Rafsanjan regions. Furthermore, socio-economic factors such as general education, farmers' specialized knowledge in pistachio nutrition, and their outlook towards the future of orchards played crucial roles in the selection of nutritional strategies.

the logit model analysis revealed that although higher general education levels increased the likelihood of using chemical and micronutrient fertilizers, this general literacy alone did not guarantee efficient decision-making regarding input usage. In contrast, specialized nutritional knowledge had a more direct and positive effect on the proper selection of fertilizer patterns. This highlights the need for targeted and practical agricultural extension and educational programs to enhance field-level decision-making among farmers.

farmers’ attitudes towards the future and their optimism regarding the sustainability of water resources emerged as a key variable influencing their willingness to invest in long-term inputs, such as organic fertilizers. Despair over water scarcity led to reduced use of long-term impact fertilizers and a tendency towards short-term planning. This finding underscores the importance of integrating social psychology into agricultural policymaking and the necessity of fostering hope while realistically informing farmers about the limitations of natural resources.

Economic evaluations indicated that most farmers underutilize chemical and organic fertilizers compared to the calculated optimal economic levels—particularly potassium and chicken manure, which demonstrated the highest marginal effects. This underutilization calls for well-structured support mechanisms such as targeted subsidies and credit facilities to promote optimal fertilizer use.

The integrated use of organic, chemical, and micronutrient fertilizers significantly improved yields. This emphasizes the importance of implementing Integrated Nutrient Management (INM) strategies in pistachio orchards. The successful application of this approach requires coordinated efforts among research centers, extension services, and agricultural policymakers.

In conclusion, this study suggests that sustainable and productive pistachio farming in southeastern Iran can only be achieved through a multidimensional and interdisciplinary approach to nutrient management—one that simultaneously considers technical, economic, and social dimensions.

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Conflict of interest

The authors declare no conflict of interest.

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