Journal of Optimization in Industrial Engineering
Vol.15, Issue 2, Summer & Autumn 2022, 147- 165
Doi: 10.22094/joie.2022.1946966.1923

Research Article

Assessing the Impact of Environmental Aspects, Land Use, and R&D Policies on Peri-Urban Agriculture Using a System Dynamics Approach

Armin Cheraghalipour,[a] Emad Roghanian[a,*]

[a] *Department of Industrial Engineering, K. N. Toosi University of Technology, Tehran, Iran*

Received **10** December 2021; Revised 26 April 2022; Accepted 27 April 2022

Abstract

Today, attention to the social and environmental aspects in addition to the economic aspect has become one of the main concerns of global organizations defending the environment and human societies, and urbanization. Also, profitability is raised as a key component in the robustness of various sectors including agricultural production. In this research, we investigate the impact of some policies and environmental aspects such as land use, pruning decisions, and research and development (R&D) on the profitability of citrus production, in the long run, using the system dynamics (SDs) model. The main contribution of this study is considering several key assumptions simultaneously in an integrated dynamics model such as the solar effect, R&D policy, pesticide effect, harvesting condition, and prune effect which is neglected or less noticed in the literature. For validation, the model's behavior is compared with collected historical observations. Statistical analysis shows that the simulated model is consistent with historical patterns. To further investigate, the Monte Carlo simulation for sensitive variables of the proposed model is implemented and finally, the model under different scenarios is examined. Various simulations have shown that changes in maximum economic yield, citrus price, and R&D policy are three important and effective agents to achieve the best performance in this sector. Also, the obtained results can help agricultural managers and the application of these interventionist policies can lead to an increase in producers' income and citrus production.

Keywords: System dynamics modeling; R&D interventions; Citrus production; Simulation; Land-use policy

1. Introduction

Citrus production as peri-urban agriculture has paramount importance in today's world, and it has become one of the most important sources of wealth generation, trade, and employment for residents of about 125 countries. Citrus fruits are one of the most economical fruits for growers, as long as the weather conditions allow other citrus fruits to look good. Today, world trade encompasses a wide range of goods and services in which agricultural products are particularly popular. Many countries in the world have been able to produce a variety of agricultural products due to favorable climatic conditions and by providing billions of dollars in foreign exchange earnings, they have met some of their import needs (FAO, 2017).

Due to the high costs of citrus orchard construction and resource constraints, increasing citrus production through increasing the productivity of the essential production factors is inevitable. On the other hand, attention to social and environmental aspects has attracted a wide range of views in addition to the economic aspect (Saavedra M., de O. Fontes, & M. Freires, 2018). Therefore, different sectors of industry are working to improve the efficiency of sustainable growth. As a result, this will not only improve the profitability of the organization or industry but also consider the efforts to protect the environment and social aspects.

Economic, technological, social, and environmental changes are increasingly called managers and policymakers to learn more as they face the complexity of systems and the gradual evolution of life. Many of the issues we face are due to the unforeseen side effects of our past performance. Also, most of the policies we use to solve important issues fail and lead to wrong solutions or new problems. Effective decision-making and learning in a world of dynamic complexity compel us to be systemic thinkers to expand the boundaries and limitations of the mental model and to use tools and equipment to better understand the complex system structure and its behaviors (Sterman, 2000; Saeedi Aghdam et al.,2020). Scientists and researchers have used a variety of methods such as mathematical programming (Cheraghalipour, Paydar, & Hajiaghaei-Keshteli, 2018, 2019), statistical (Etemadnia, Goetz, Canning, & Tavallali, 2015; Teimoury, Nedaei, Ansari, & Sabbaghi, 2013), and system dynamics planning (Ibragimov, Sidique, & Tey, 2019; Mohammadi, Arshad, Bala, & Ibragimov, 2015) to improve the performance and formulation of appropriate programs for the agricultural sector. One of the most common uses and useful simulation methods is system dynamics modeling. It is a method for business modeling and policy analysis

*Corresponding author Email address: e_roghanian@kntu.ac.ir

based on feedback systems theory. System dynamics require careful design and construction of innovative models with high interactive variables.

Since food and agricultural products play a very important role in the food basket of the world's people, the concern of world organizations to plan and improve the sector has prompted many researchers to work in this field. Researchers, therefore, plan and develop conceptual and mathematical models to improve productivity, goods production, demand responsiveness, shortage reduction, cost reduction, and profits increment. For example, in a hybrid approach, Walters et al. (2016) formulate a system dynamics model by integrating quantitative and qualitative information and examining the impact of sustainability aspects on the agricultural sector. Their model is assessed to find the impact of each sustainability factor in several different construction systems such as agricultural products, livestock systems, and a combination of these two elements. The outcome showed that only agricultural products follow sustainability. On the other hand, Rich et al. (2018) investigated the features of urban agriculture, and they looked at some of the political experiments for this growing event. Moreover, they provided a system dynamics model to check feedback between the processes involved in changing the food system and the extensive processes such as land use and planning. They presented a qualitative perception of the proposed model principles and techniques for describing the dynamic conditions and issues of the urban farm value chain in New Zealand.

Recently, Ibragimov et al. (2019) investigated the efficiency of oil palm production using a system dynamics modeling approach. To do this, they analyzed the actual results with the simulation results using a case study in Malaysia and simulated their proposed dynamic model in the VENSIM software. One of their important results was the report that research and development was the key factor in this planning. Moreover, Martínez-Jaramillo et al. (2019) proposed a system dynamics model to measure the impacts of biofuel generation on food safety. Their model studies the behavior of livestock farming, biofuel, and food creation and it was verified using a case study in Colombia. The outcomes illustrated that the allocated land for agriculture is reduced based on biofuels presentation in this country. They provided several scenarios to measure the efficiency of land use based on biofuel production. They used VENSIM software to code their dynamic model and give some insights to managers of their country.

Moreover, using a dynamic system model, Jampani et al. (2020) analyzed land-use change in a rural catchment area in India to study the impact of land-use changes and groundwater on vegetable and rice cultivation. Their results show that the uncontrolled construction of buildings in these agricultural landscapes due to the proximity to the city reduces the cultivated land. At the same time, this shortage causes the conversion of barren lands to agricultural lands. To maintain the texture and landscape of agriculture, in the long run, construction should be reduced.

Recently, Pluchinotta et al. (2021), In a collaborative process, explored the challenges of urban water management in the United Kingdom using the SDs model. Using their dynamic model, they sought to reduce the consumption of residential drinking water in the studied city by taking into account social, environmental, and economic policies. In another study, Abebe et al. (2021) acknowledged that city agencies have a responsibility to anticipate specific cash flows for post-hurricane actions in storm-prone countries such as Canada before an accident occurs. Therefore, in their research, they presented a new dynamic model including causal relationships and mathematical formulation to estimate the potential for storm cost determination in Canada by this simulation approach. As is clear, the importance of agricultural production in human society is undeniable, and system dynamics modeling is also a very practical method that enables managers to make long-term decisions for this sector by observing simulation behaviors. Therefore, research in this area can be very useful for farmers, managers, and countries. Given the scarcity of research in this area, further research must be conducted, thus, some of these relevant researches are classified in Table 1. It is worth saying that, all of the reported research in this Table are in the field of agricultural production using system dynamics modeling and they are compared with others in terms of several assumptions including considering the effect of water resource, soil, land-use, solar effect, worker, R&D policy, fertilizer, pesticide, harvesting condition, cost, and prune.

As is clear, based on Table 1, it can be found that about 88% of these researches did not consider the solar effect. Also, only 41% of these researches considered the worker effect, and also about 12% of those studied the R&D policy in their formulation. Moreover, only one research considered the pesticide effect. Also, about 35% of them paid attention to the harvesting effect and there is no research to address the prune effect in modeling. Therefore, the novelties of this study can be presented based on the reported research gaps.

- A novel system dynamics model for sustainable citrus production is developed.
- Several neglected assumptions in the literature such as the effect of solar, R&D policy, pesticide, harvesting conditions, and prune are considered.
- The Monte Carlo simulation for sensitive variables of the proposed model is implemented.
- A real-world case study in Iran is applied.

Given the importance mentioned above, in this research, through a systematic approach, we investigate the impact of productivity growth drivers on its related factors using the system dynamics model.

Table 1
Reviewing several relevant researches of agricultural production using system dynamics

Reference	Effect of											Sector
	Water	Soil	Land-use	Solar ref.	Worker	R&D	Fertilizer	Pesticide	Harvesting	Cost	Pruning	
(Saysel, Barlas, & Yenigün, 2002)	*		*		*		*	*				Agricultural production
(Shi & Gill, 2005)	*	*	*		*		*		*	*		Ecological agriculture
(Antle & Stoorvogel, 2006)	*	*					*			*		Agricultural production
(C. Rozman et al., 2008)		*	*				*			*		Organic agriculture
(Li, Dong, & Li, 2012)	*		*	*			*			*		Eco-agriculture system
(Wei, Yang, Song, Abbaspour, & Xu, 2012)	*	*	*							*		Water resources
(Č. Rozman et al., 2013)		*	*				*			*		Organic farming
(Mohammadi et al., 2015)			*		*		*		*	*		Oil palm
(Dace et al., 2015)		*	*				*			*		Agricultural GHG emissions
(Chapman & Darby, 2016)	*						*			*		Rice
(Walters et al., 2016)	*	*	*		*				*	*		Crop production
(Kotir et al., 2016)	*	*	*		*	*				*		Water resources
(Kopainsky, Hager, Herrera, & Nyanga, 2017)	*		*							*		Food systems
(Huang et al., 2017)	*	*	*	*						*		Urban agriculture
(Rich et al., 2018)			*						*	*		Urban agriculture
(Pluchinotta, Pagano, Giordano, & Tsoukiàs, 2018)	*		*		*					*		Irrigation water
(Moein, Asgarian, Sakieh, & Soffianian, 2018)	*	*	*						*	*		Agricultural production
(Ibragimov et al., 2019)	*	*	*	*	*	*	*		*	*		Oil palm
(Martínez-Jaramillo et al., 2019)		*	*						*			Biofuels and food
(Jampani et al., 2020)	*	*	*		*					*		Agricultural products
(Pluchinotta et al., 2021)	*	*								*		Residential drinking water
(Abebe et al., 2021)	*	*			*					*		Stormwater
This study	*	*	*	*	*	*	*	*	*	*	*	Citrus production

For this purpose, a system dynamics model has been designed for citrus production in which factors such as water, land use, and harvesting are considered as the environmental aspects. Besides, worker costs, fertilizer and pesticide costs, and the income of the producers are raised as economic aspects. Research and development (R&D) policy and the amount of product needed are also considered as the social aspects. Finally, using the simulation of the proposed model, the impact of the relevant factors on citrus production is evaluated. Also, compared with the real case study data, the simulation validation is investigated. Statistical analysis shows that the simulated model is consistent with historical patterns. To further investigate the Monte Carlo simulation for sensitive variables is performed, and the proposed model is finally implemented under different scenarios. As observed, the unripe citrus area follows the overshoot and collapse behavior and the other mentioned variables include ripe citrus area, total citrus area, total fresh fruit production, expected cost, and producers' income follow the S-shape behavior. Moreover, a 12% increase in local manufacturing input was practically ineffectual and was tended to the base case for all six variables. However, three key scenarios consisting of a 10% increase in maximum economic yield, a 5% increase in citrus price, and an increase in investment in R&D were very effective to move all graphs toward the left side. Also, another scenario that includes a 5% increase in wage had led to the graph being moved to the right side. Finally, various simulations have shown that changes in maximum economic yield, citrus price, and R&D policy are three important and effective agents to increase citrus production and other key variables.

In the remainder of this study, the second section discusses the research methodology including the general structure of the proposed model and the stocks-flows model. The relationships between variables are also presented in this section. The third section describes the results of the simulation, and the fourth section discusses simplified modeling. Finally, the fifth section presents conclusions and suggestions for future research.

2. Materials and Methods

In this section, at first, the causal loop diagram is figured and its related feedback loops are described. Then, using the mentioned diagram, the stock-and-flow diagram can be illustrated and its related equations for simulating the proposed model are reported.
Moreover, to the best of our knowledge, the pruning parameter is neglected in the literature and its importance is reported as follows. In many orchards, the trees are left free, without the slightest pruning. In this case, the trees have lost their fertility and the branches continue to grow in a natural and wild state under the influence of environmental conditions and go to both sides. The fruits formed on those branches are usually small, scattered, and devoid of the desired flavor and color. These trees seem to have a physiological balance between their roots and their environment. However, the amount of product and its quality has decreased, and trees are gradually becoming more susceptible to malnutrition and their lifespan is reduced. Usually, earlier than pruned trees, their branches are damaged by adverse environmental factors. Also, trees that are not pruned are significantly delayed in fruiting age and are practically fertilized later than pruned trees. Also, in such trees, the necessary operations to control plant pests were difficult due to the large number of branches and leaves. Pruning fruit trees can have several benefits such as increasing tree life, increasing the number of products, increasing fruit quality, and preventing fruit loss.

2.1. Problem articulation and causal-loop diagram

Here, a system dynamics model for sustainable citrus production is provided which includes environmental elements (water, soil, and land use), economic elements (agricultural input costs), and social elements (R&D policies). The purpose of the model is to test the impact of some policies such as land use, pruning decision, and R&D on the profitability of sustainable citrus production in the long run. Furthermore, the model boundary contains all components present in the final model. Using a brainstorm, the model boundary for the citrus production problem is obtained and shown in Table 2.
It is important to remember that the model is not built during the conceptualization stage. Here, only the relevant information about the problem is identified. The final system dynamics model of the sustainable citrus production problem may have a few additions and deletions from the components listed in Table 2.

Table 2
Components for the citrus production problem

Endogenous components	Exogenous components
Available citrus area (S)	Total area under cultivation (F)
Citrus area (F)	Yield loss (F)
Net development (F)	Production cost (F)
Replanting (F)	Substitute trees' profit (F)
Total fresh fruit production (F)	R&D condition (F)
Citrus price (F)	Maximum economic productivity (F)
Citrus profit (F)	Harvesting effect (F)
Relative profit (F)	Solar effect (F)
R&D policy (F)	Soil and water effect (F)
Desired productivity change (F)	Pesticides and fertilizers effect (F)
Potential fresh fruit yield (S)	
Implemented fresh fruit yield (F)	
Actual fresh fruit yield (F)	
Productivity gap (F)	
(S): stock	(F): flow

The components list is just a guideline and not a strict frame for the proposed model. On the other hand, in this problem, the reference mode (historical performance of the key variables) for some available variables looks like Fig 1. Only the historical data of these two variables are available, which are shown in this figure, and according to the purpose of the model, these two variables are important.

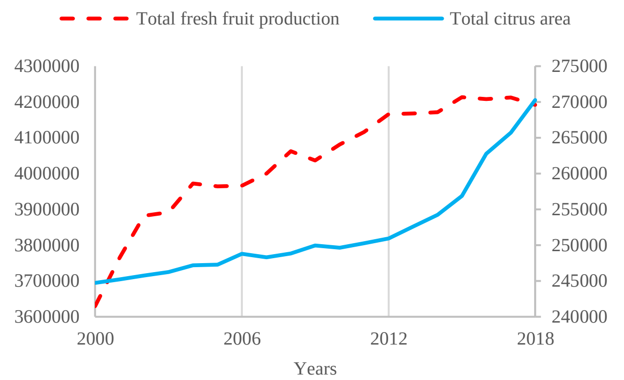


Fig 1. Reference Mode for a citrus production problem

When a dynamic model is implemented, the reference mode or dynamic behavior of the system is generated by the endogenous structure (S. tooranloo, K. Takalo, & Mohyadini, 2022). Moreover, the model's purpose is to check the model behavior in the long run and the reference mode is also available for 18 years to show the main trend of variables. If the month is a time period, the behavior of the reference mode is linear, and the main trend of variables cannot be found. Therefore, the time horizon of the model is between [2000, 2100] based on the year. Also, the integration error is equal to 1 and the model is discrete in time. Finally, based on the above-mentioned dynamic hypothesis and the explanation of the feedback loops in follow, the system dynamic model can be reported.

Understanding cause-and-effect relationships are one of the main steps in a system dynamics approach (Sterman, 1994). To this end, the causal loop diagram, which describes the main cause and effect of the citrus production system in Iran, is shown in Fig 2.

As is shown, the most important elements of the citrus production system are citrus production, the area under cultivation, and profitability. The slow S-shaped growth of the area and citrus production in Iran is illustrated by four reinforcing and two balancing loops (see Figure 2). When citrus production, together with price and cost, creates more relative output for producers, they are encouraged to follow the 'R3' loop of production feedback. Similarly, when citrus production yields high relative profits, producers tend to expand areas (R1) and replanting (R2). Despite the stagnating in citrus productivity growth, there has been a significant increase in citrus production only due to the development of the area under cultivation. The development of the area is shown in the primary expansion stage of loop 'R1' using the available citrus area. Due to the limited amount of total area under cultivation, development after the plenty stage (caused by 'R1') inclines to become saturated (caused by the 'B1'). Many products such as rice, oil palm, and cocoa use these feedback loops, and the replaced area under cultivation are also restricted (Zabel, Putzenlechner, & Mauser, 2014).

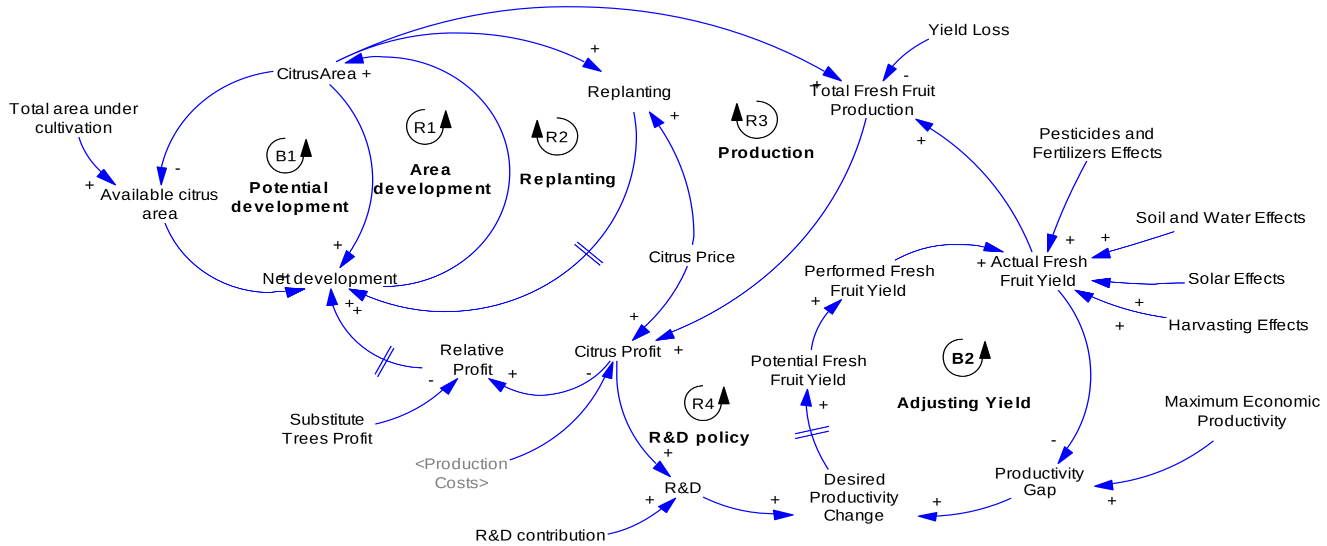


Fig 2. The causal loop diagram of the Citrus Production System in Iran

Citrus productivity in the cultivated area has slow progress which can be stated by drastic problems in productivity agents such as worker and non-worker resources. Also, other factors such as pesticides, fertilizers, soil water, harvesting, and solar effects (Included in 'B2') and R&D policy (Included in 'R4') can change productivity. The dynamics of applying area per time are changed by numerous agents that are amplified by weak loops with low efficiency. This matter makes the need for increasing the area of cultivation and therefore creates competition for cultivating areas among varied products. Besides, the causal-loop diagram (see Fig 2) indicates slow growth in citrus productivity, and land-use saturation which is based on the hypothesis made about how the real citrus system works. Also, it should be noted that B_i and R_i represent the balancing and reinforcing loops, respectively.

2.2. The stock-and-flow diagram

In this section, two main segments of the stock-and-flow diagram for citrus production in Iran are illustrated in Figures 3 and 4. In the first segment, the related feedback loops of the area for cultivation, total fresh fruit production, producers' income, and profitability are shown. While, the second segment shows the related feedback loops of solar effects, pruning effects, water shortage effects, harvesting frequency, worker effects, productivity changes, R&D policy, using nutrition such as fertilizers and pesticides, and so on. Also, the following integral equation (1) is used to simulate the stock-and-flow diagram.

$$Stock(t) = \int_{t_0}^{t} \left[Inflow(s) - Outflow(s) \right] ds + Stock(t_0) \tag{1}$$

The Stock variable is represented by a rectangle and the flow rate variable is specified by a valve icon.

According to the stock-and-flow diagram in Figure 3, the main equations relating to land use or area are reported in equations (2) to (7). As is clear in equation (2), total citrus area (ha) is equal to the summation of unripe citrus area (ha) and ripe citrus area (ha), which the initial values and formulas for each of them are reported in equations (3) and (4), respectively. Also, equation (5) is related to the abandoned area (ha) which shows the integral of the difference between the effective flows such as crop erosion rate (ha/Year) and replanting rate(ha/Year). Moreover, the other trees areas (ha) can be changed to the unripe citrus area (ha) using a transformation rate (ha/Year) as shown in equation (6). Besides, the new planting reduces the amount of uncultivated area (ha) as presented in equation (7).

On the other hand, as equation (8) shows, the replanting rate (ha/Year) is influenced by the abandoned area (ha), normal replanting fraction, and the effect of profitability on replanting. Based on equation (9), it can be found that crop erosion rate (ha/Year) by dividing the ripe citrus area by the citrus lifespan is calculated. Moreover, new planting (ha/Year) and ripening rate (ha/Year) are given in the equations (10) and (11), respectively. Furthermore, the expected cost (Rial/Year) is the summation of pesticide and fertilizer cost and worker cost as given in equation (12). Also, the Producers' income (Rial/Year) is achieved by multiplying total fresh fruit production and citrus price as equation (13). Finally, expected profitability (dmnl) can be calculated using two previously mentioned variables values as equation (14). Also, the rest of the variables are shown in equations (15) to (18).

Moreover, according to the stock-and-flow diagram in Figure 4, the main equations relating to other variables are reported as follows. Equation (19) refers to the yield gap (ton/(Year*ha)) calculation by subtracting maximum economic yield and actual fresh fruit. Equation (20) implies that actual fresh fruit (ton/ha/Year) is related to several environmental agents such as implemented PY, the effect of EUN, the effect of HF, the effect of water shortage, and the effect of SR, and effect of the worker. Equation (21) shows that performed potential yield (ton/ha/Year) has a direct relationship with potential yield, and time to implement new variety under a SMOOTH function. This function displays the average time and expresses the expectance. Also, equations (22) and (23) display the potential yield (ton/ha/Year) and Change in potential yield (ton/ha/Year/Year), respectively.

Total Citrus Area=Unripe Citrus Area (UCA)+Ripe Citrus Area (2)

Unripe Citrus Area (UCA)= INTEG (Transformation (Tr)+New Planting (NP)+Replanting Rate- Ripening Rate (RR), Initial value) (3)

Ripe Citrus Area= INTEG (Ripening Rate (RR)- Crop Erosion Rate, Initial value) (4)

Abandoned Area= INTEG (Crop Erosion Rate-Replanting Rate, Initial value) (5)

Other Trees Areas (OTA)= INTEG (-Transformation (Tr), Initial value) (6)

Uncultivated Area (UA)= INTEG (-New Planting (NP), Initial value) (7)

Replanting Rate= Abandoned Area × Normal Replanting Fraction × Effect of Profitability on Replanting (8)

Crop Erosion Rate=Ripe Citrus Area/Citrus Lifespan (9)

New Planting (NP)=Unripe Citrus Area (UCA)×Normal NP Fraction×Effect of UA on NP×Effect of Profitability on NP (10)

Ripening Rate (RR)=Unripe Citrus Area (UCA)/Ripening time (11)

Expected Cost=(Pesticides and Fertilizers Cost + Worker Cost) (12)

Producers Income=Total fresh fruit production × Citrus Price (13)

Expected Profitability=(Producers Income-Expected Cost)/Expected Cost (14)

Transformation (Tr)=Unripe Citrus Area × Normal Tr Fraction × Effect of OTA on Tr × Effect of Profitability on Tr (15)

*Normal Tr Fraction=IF THEN ELSE(Time>=*2008, 0, 0.02*)* (16)

Normalized OTA=Other Trees Areas (OTA)/Initial OTA (17)

Normalized UA= Uncultivated Area (UA)/Initial UA (18)

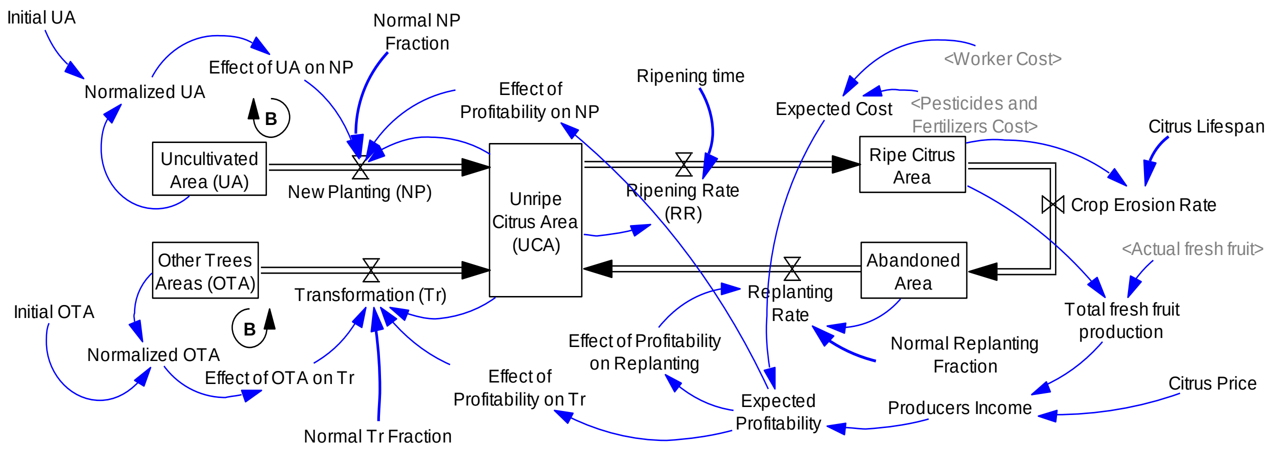


Fig 3. The first segment of the stock-and-flow diagram for citrus production

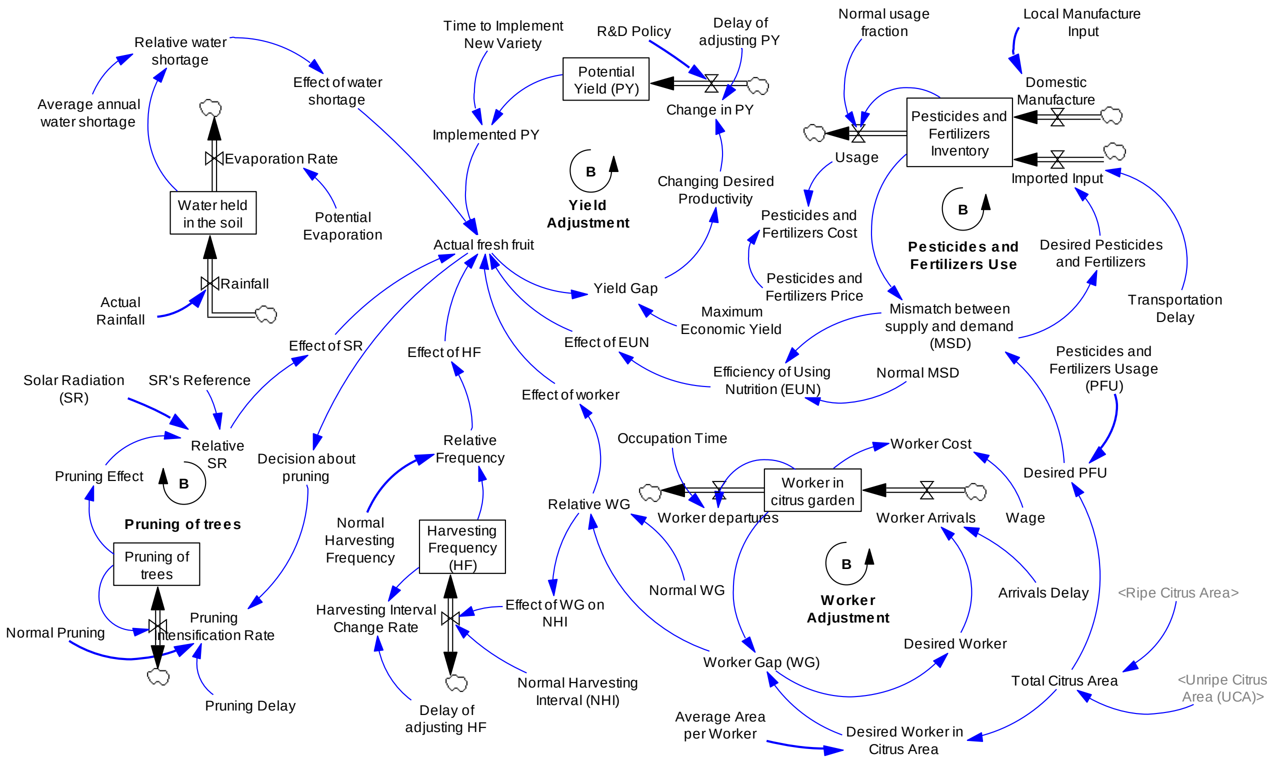


Fig 4. The second segment of the stock-and-flow diagram for citrus production

Yield Gap=Maximum Economic Yield-Actual fresh fruit (19)

Actual fresh fruit= Implemented Potential Yield × Effect of EUN × Effect of HF × Effect of water shortage × Effect of SR × Effect of worker (20)

Implemented Potential Yield =SMOOTH(Potential Yield (PY), Time to Implement New Variety) (21)

Potential Yield (PY)= INTEG (Change in PY, Initial value) (22)

Change in PY=Changing Desired Productivity × R&D Policy/Delay of adjusting PY (23)

Also, as is presented in equations (24) and (25), we estimate citrus price and pesticide and fertilizer price for 2020 to 2050 based on available values from 2000 to 2015, and those simulated using the LOOKUP functions as Fig 5.

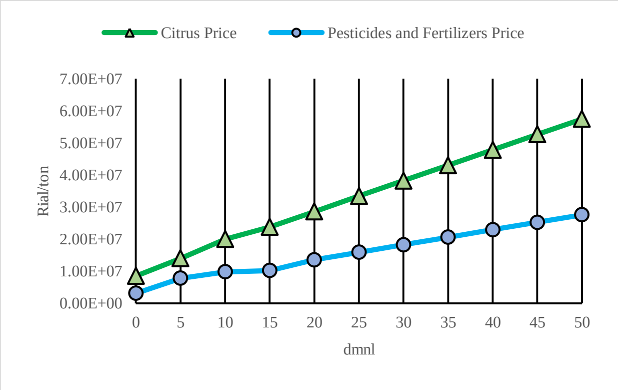


Fig 5. The estimated citrus price and pesticides and fertilizers price

Moreover, as presented in equations (26) to (28), the effects of profitability on NP, Replanting, and Tr are achieved using the LOOKUP functions as shown in Fig 6. Similarly, as is accessible in equations (29) to (32), the effect of water shortage, worker, and EUN on yield along with the effect of WG on NHI are attained using the LOOKUP functions as shown in Figure 7.

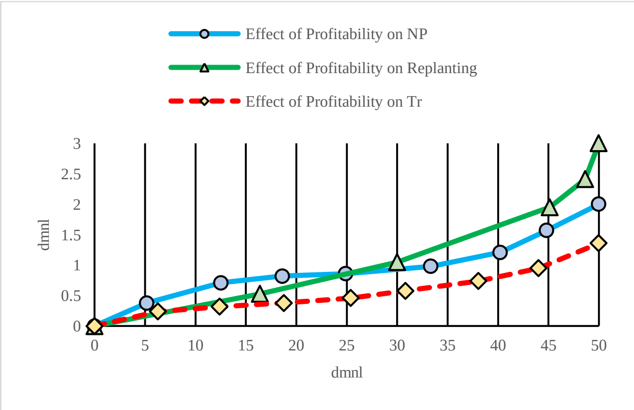


Fig 6. The effect of profitability on New Planting (NP), Replanting, and Transformation (Tr)

Moreover, the effect of HF, SR, and pruning on yield and decision about pruning are reached using the LOOKUP function as presented in equations (33) to (36). Since the trend of these variables is linear, their graphs are not plotted. Besides, the effect of OTA on Tr along with the effect of UA on NP is shown in Figure 8. As is accessible in equations (37) and (38), these variables are attained using the LOOKUP functions.

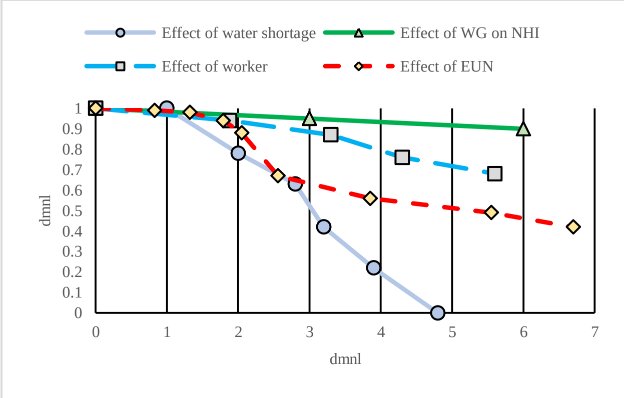


Fig 7. Effect of water shortage, worker, and Efficiency of Using Nutrition (EUN) on yield along with the effect of Worker Gap (WG) on Normal Harvesting Interval (NHI)

Besides, related variables to labor such as worker cost (Rial/Year), worker arrivals (worker/Year), worker gap (worker), the worker in the citrus garden (worker), worker departures (worker/Year), desired worker (worker), the desired worker in the citrus area (worker), and relative WG (dmnl) are presented in equations (39) to (46). Furthermore, related variables about pesticides, fertilizers, and using nutrition are presented in equations (47) to (55).

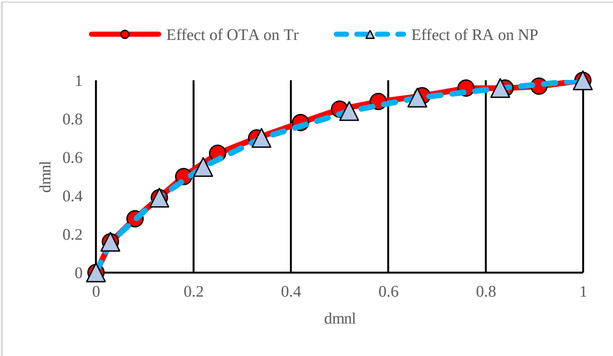


Fig 8. Effect of Other Trees Area (OTA) on Transformation (Tr) along with the effect of Uncultivated Area (UA) on New planting (NP)

In equations (52), 0.55 means that there is a need to import 55% fertilizer and pesticides. Finally, the rest of the variables' formulation such as environmental agents, pruning, and harvesting are provided in equations (56) to (67).

Citrus Price= WITH LOOKUP (Time/Initial Year) (24)
([(2000,0)-(2050, 6e+07)],(2000, 85e+05),(2005, 14e+06),(2010, 20e+06),(2015,2381e+04),
(2020, 2862e+04),(2025, 3343e+04),(2030, 3824e+04),(2035, 4305e+04),(2040, 4786e+04),
(2045, 5267e+04),(2050, 5748e+04))

Pesticides and Fertilizers Price= WITH LOOKUP (Time/Initial Year) (25)
([(2000,0)-(2050, 6e+07)],(2000, 31e+05),(2005, 78e+05),(2010, 98e+05),(2015, 1023e+04),
(2020, 1358e+04),(2025, 1592e+04),(2030, 1826e+04),(2035, 2060e+04) ,(2040, 2294e+04) ,
(2045, 2527e+04) ,(2050, 2761e+04))

Effect of Profitability on NP= WITH LOOKUP (Expected Profitability) (26)
([(0,0)-(50,2)],(0,0),(5.18,0.38),(12.54,0.71),(18.61,0.82),(24.89,0.86),(33.35,0.98),(40.23,1.21)
,(44.82,1.57),(50,2))

Effect of Profitability on Replanting= WITH LOOKUP (Expected Profitability) (27)
([(0,0)-(50,3)],(0,0),(16.4,0.53),(30,1.05),(45.15,1.95),(48.65,2.41),(50,3))

Effect of Profitability on Tr= WITH LOOKUP (Expected Profitability) (28)
([(0,0)-(50,2)],(0,0),(6.3,0.24),(12.4,0.32),(18.78,0.38),(25.42,0.46),(30.82,0.58),(38.05,0.74),
(44.02,0.95),(50,1.36))

Effect of water shortage= WITH LOOKUP (Relative water shortage) (29)
([(0,0)-(5,1)],(0,1),(1,1),(2,0.78),(2.8,0.63),(3.2,0.42),(3.9,0.22),(4.8,0))

Effect of WG on NHI= WITH LOOKUP (Relative WG) (30)
([(0,0.8)-(6,1)],(0,1),(3,0.95) (6,0.9))

Effect of worker= WITH LOOKUP (Relative WG) (31)
([(0,0.6)-(6,1)],(0,1),(1.88,0.94),(3.3,0.87),(4.3,0.76),(5.6,0.68))

Effect of EUN= WITH LOOKUP (Efficiency of Using Nutrition (EUN)) (32)
([(0,0)-(7,1)],(0,1),(0.83,0.99),(1.32,0.98),(1.79,0.94),(2.05,0.88),(2.56,0.67),(3.85,0.56),
(5.55,0.49),(6.7,0.42))

Effect of HF= WITH LOOKUP (Relative Frequency) (33)
([(0.71,0)-(1,2)],(0.71,1.2),(0.855,1.1),(1,1))

Effect of SR= WITH LOOKUP (Relative SR) (34)
([(0.8,0.8)-(1.5,1.2)],(0.8,0.95),(1,1),(1.23,1.11),(1.5,1.2))

Pruning Effect= WITH LOOKUP (Pruning of trees) (35)
([(0,0.8)-(0.9,1)],(0,0.8),(0.43,0.9),(0.86,1))

Decision about pruning= WITH LOOKUP (Actual fresh fruit/FF unit) (36)
([(15,0)-(22,1)],(15,1),(16,0.85),(17,0.7),(18,0.55),(19,0.4),(20,0.25),(21,0.1),(22,0))

Effect of OTA on Tr= WITH LOOKUP (Normalized OTA) (37)
([(0,0)-(1,1)],(0,0),(0.03,0.16),(0.08,0.28),(0.13,0.39),(0.18,0.5),(0.25,0.62),(0.33,0.7),(0.42,0.78),
(0.5,0.85),(0.58,0.89),(0.67,0.92),(0.76,0.96),(0.84,0.96),(0.91,0.97),(1,1)))

Effect of UA on NP= WITH LOOKUP (Normalized UA) (38)
([(0,0)-(1,1)],(0,0),(0.03,0.16),(0.13,0.39),(0.22,0.55),(0.34,0.7),(0.52,0.84),(0.66,0.91),(0.83,0.96),(1,1))

Worker Cost=Worker in citrus garden × Wage (39)

Worker Arrivals =Desired Worker/ Arrivals Delay (40)

Worker Gap (WG)=Desired Worker in Citrus Area-Worker in citrus garden (41)

Worker in citrus garden= INTEG (Worker Arrivals -Worker departures, Initial value) (42)

Worker departures =Worker in citrus garden/Occupation Time (43)

Desired Worker=Worker Gap (WG) (44)

Desired Worker in Citrus Area=Total Citrus Area/Average Area per Worker (45)

Relative WG=Worker Gap (WG)/Normal WG (46)

Desired Pesticides and Fertilizers=Mismatch between supply and demand (MSD) (47)

Desired PFU=Total Citrus Area × Pesticides and Fertilizers Usage (PFU) (48)

Domestic Manufacture=Local Manufacture Input (49)

Efficiency of Using Nutrition (EUN)=Mismatch between supply and demand (MSD)/Normal MSD (50)

Usage=Pesticides and Fertilizers Inventory × Normal usage fraction (51)

Imported Input=Desired Pesticides and Fertilizers × 0.55*/Transportation Delay* (52)

Mismatch between supply and demand (MSD)=Desired PFU-Pesticides and Fertilizers Inventory (53)

Pesticides and Fertilizers Cost=Usage × Pesticides and Fertilizers Price (54)

Pesticides and Fertilizers Inventory= INTEG (Domestic Manufacturer + Imported Input-Usage, Initial value) (55)

Evaporation Rate=Potential Evaporation (56)

Harvesting Frequency (HF)= INTEG (Harvesting Interval Change Rate, Initial value) (57)

Harvesting Interval Change Rate=(Normal Harvesting Interval (NHI) × Effect of WG on NHI-Harvesting Frequency (HF))/Delay of adjusting HF (58)

Changing Desired Productivity=Yield Gap (59)

Pruning Intensification Rate=(Normal Pruning × Decision about pruning-Pruning of trees)/Pruning Delay (60)

Pruning of trees= INTEG (Pruning Intensification Rate, Initial value) (61)

Rainfall=Actual Rainfall (62)

Relative Frequency=Harvesting Frequency (HF)/Normal Harvesting Frequency (63)

Relative SR=Solar Radiation (SR) × Pruning Effect/SR's Reference (64)

Relative water shortage=Water held in the soil/Average annual water shortage (65)

Total fresh fruit production=Ripe Citrus Area × Actual fresh fruit (66)

Water held in the soil= INTEG (Rainfall-Evaporation Rate, Initial value) (67)

2.3. The case study and validation

In this section, the initial values and values of constant variables are reported using a real-world case study in Iran. Here, we consider all citrus gardens of this country base on the report of the Ministry of Agriculture-Jihad of Iran (MAJI) ("Ministry of Agriculture-Jahad of Iran," n.d.). According to this report, the utility of the area regardless of the climate limitations in Iran is illustrated in Figure 9. When the land utility based on soil and topographic constraints is measured, 120 million hectares (74%) of the country's land has a lower quality for agriculture. Moderate-use land accounts for about 17.2 million hectares (10.6%) of the country and high-quality (good and very good) land accounts for about 5.8 million hectares (3.5%) of the entire country.

Finally, the total area of arable land in Iran is estimated to be about 16.462 million hectares by MAJI, which among them 1,775,000 hectares are related to the fruit gardens, and 14,687,000 hectares are under cultivation of other crops. Furthermore, 260,000 hectares are under cultivation of Citrus which 36,890 hectares are Unripe Citrus Areas, and 221,816 hectares are Ripe Citrus Areas. Besides, 2,500 hectares are related to the abandoned area. Also, 1,515,000 hectares are related to other trees areas. On the other hand, based on (https://tradingeconomics.com/iran/precipitation) the amount of actual rainfall in Iran is about 250-500 mm/year, and which average annual water shortage is about 450 mm/year. Moreover, according to (Young, n.d.), Citrus Lifespan is assumed by 100 years. Therefore, the initial values of stock variables are presented in Table 3. Also, the values of other constant variables are reported in Table 4. Also, the (Dmnl) represents the dimensionless parameters.

As noted, these values come from data provided by the Ministry of Agriculture's Jihad statistics, the Bureau of Statistics and Information Technology, the FAO's statistics, government reports, and gardens visits (Agriculture Jihad, 2016; FAO, 2017).

Model validation tests were performed using various informal and formal steps that include comparing model expectations with historical behavior, testing whether the model produces plausible behavior, and verifying the quality of the parameter values (Bala, Arshad, & Noh, 2017; Saysel et al., 2002; Senge & Forrester, 1980; Hosseini, & Paydar, 2022).

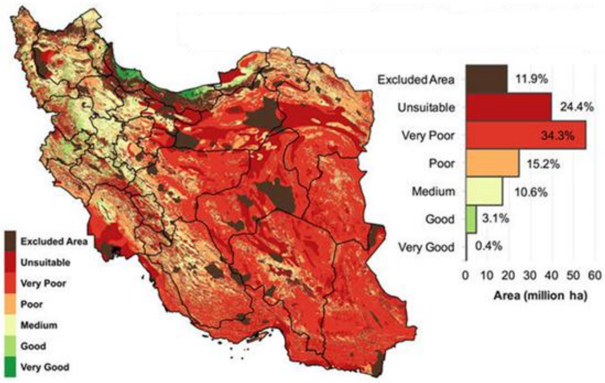


Fig. 9. The utility of land use regardless of the climate limitations in Iran

Model validation tests were performed using various informal and formal steps that include comparing model expectations with historical behavior, testing whether the model produces plausible behavior, and verifying the quality of the parameter values (Bala, Arshad, & Noh, 2017; Saysel et al., 2002; Senge & Forrester, 1980).

After introducing the formulas and the values of the variables, it is time to simulate the dynamics model. But before simulating the model under different scenarios, we first need to validate the behavior of the simulated model.

To this end, the simulated results of two key variables include total citrus area and total fresh fruit production are compared with historical data obtained from MAJI. As these outcomes show (see Figure 10), the simulated results are in good agreement with their historical data, which indicates the validity of the implemented simulation. Moreover, according to Table 5, the most commonly used statistical tests in this field have been used to further approval.

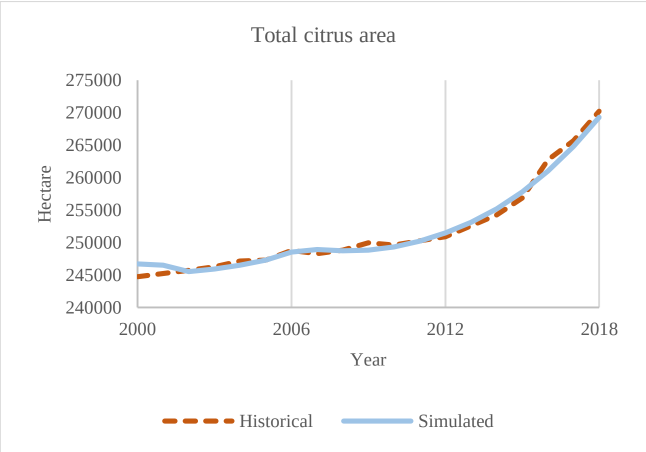
Table 5 indicates that the values of RMSPE for these two variables (total citrus area and total fresh fruit production) are 0.4% and 0.9%, respectively. Also, the results of "Theil inequality statistics" show that the values of unequal variation (U^S) for these two variables are 18.6 % and 24.1%, and the values of bias variation (U^M) for these two variables are 0.03 % and 0.24%, respectively. These outcomes imply that the simulated results are in suitable agreement with their historical data and the existed errors are just related to the unequal covariation and by point change that has occurred. Since the SD model only examines the long-run behavior, so the cyclical pattern of historical data is not taken into account.

Table 3
The initial values of related stock variables

Stock Variables	Initial values	Stock Variables	Initial values
Unripe Citrus Area (UCA)	36,890 ha	Potential Yield (PY)	16 ton/ha/Year
Ripe Citrus Area	221,816 ha	The worker in a citrus garden	200,000 worker
Abandoned Area	2,500 ha	Pesticides and Fertilizers Inventory	472,000 ton
Uncultivated Area (UA)	14,687,000 ha	Harvesting Frequency (HF)	10 days
Other Trees Areas (OTA)	1,515,000 ha	Pruning of trees	1 Dmnl
Water held in the soil	150 mm		

Table 4
The values of other variables

Variables	Values	Variables	Values
Initial OTA	1,515,000 ha	R&D Policy	1 Dmnl
Initial UA	14,687,000 ha	Potential Evaporation	1900 mm/Year
Ripening time	6 Year	Normal usage fraction	1 (1/Year)
Local Manufacture Input	256,000 ton/Year	Normal WG	32000 workers
Maximum Economic Yield	18 ton/ha/Year	Occupation Time	5 Year
Actual Rainfall	300 mm/Year	Delay of adjusting HF	1 Year
Average annual water shortage	450 mm	Delay of adjusting PY	7 Year
Average Area per Worker	1 ha/worker	Arrivals Delay	1 Year
Transportation Delay	1 Year	Wage	16e+07 Rial/worker/Year
Solar Radiation (SR)	15 W/(m 2)	Time to Implement New Variety	1 Year
SR's Reference	13 W/(m 2)	Normal HF	10 days
Pesticides and Fertilizers Usage	0.385 ton/ha	Normal Harvesting Interval	10 days
Normal MSD	236,000 ton	Normal Pruning	1 Dmnl
Normal NP Fraction	0.8 Dmnl/Year	Normal Replanting Fraction	0.8 Dmnl/Year
Citrus Lifespan	100 Year	Pruning Delay	1 Year



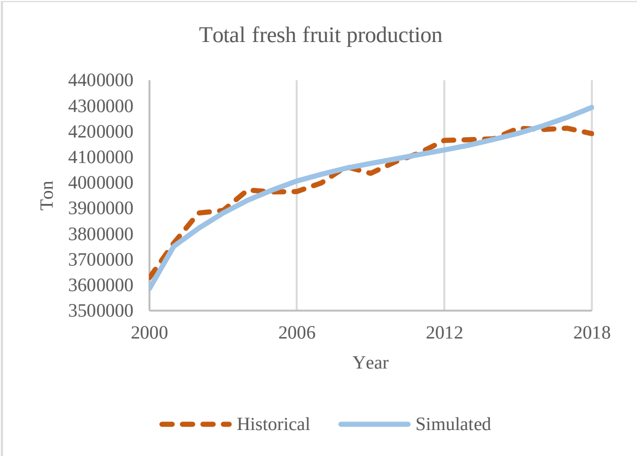


Fig 10. Verifying simulated values using historical amounts

Table 5
The statistical results of simulation and historical data

Variable	RMSPE (%)	Theil inequality statistics		
		U^C (%)	U^S (%)	U^M (%)
Total citrus area	0.004	0.869	0.186	0.0003
Total fresh fruit production	0.009	0.812	0.241	0.0024

Therefore, there is no concern for the unequal variation error component, because the model can exactly reproduce the average and trend.
Furthermore, we simulate these two key variables using the Monte Carlo approach to check the behavior of the model under several parameters as shown in Figure 11. Monte Carlo simulations are used to model the probability of different outcomes in a process that cannot easily be predicted due to the intervention of random variables. It is a technique used to understand the impact of risk and uncertainty in prediction and forecasting models. This can be very helpful in understanding the behavioral boundaries of a model and testing the robustness of model-based policies.

After the analysis, we found that the factors affecting these two variables can be listed as 'normal harvesting frequency', 'solar radiation (SR)', 'normal replanting fraction', 'Citrus lifespan', 'average area per worker', 'normal NP fraction', and 'pesticides and fertilizers usage'. In this simulation, the mentioned parameter ranges are used as U~[5,15], U~[10,20], U~[0.5,2], U~[80,120], U~[1,3], U~[1,2], and U~[0.2,0.8], respectively. This figure shows that the amount of all nominated parameters is obvious in the scope of 50-100%. For example, as seen in 2014, total citrus area (ha) is a number in the range of (240000, 380000) with a 50% probability, while this variable is in the range of (85000, 438000) with a 100% probability. Based on the mentioned properties, it is clear that the behaviors and results of the proposed model are consistent with historical patterns. Therefore, the efficiency of the proposed theory is proved and it can be used for forecasting the behavior of the framework in the next years. So, this model can help managers to make better decisions.

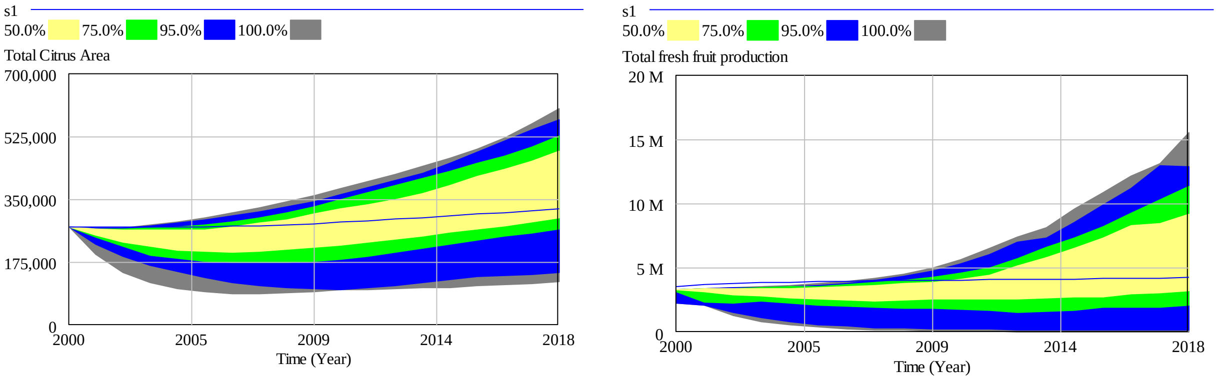


Fig 11. The simulation results of the Monte Carlo approach per 50 runs (s1 is the Base Case)

3. Results and Discussion

In this section, the simulation results are reported and a brief discussion about related results is presented. To this end, at first, several effective scenarios in the problem are designed, and the model behavior is presented. Given that 'R&D policy' is one of the most important determinants of model performance, the first scenario focuses on the impacts of increased investment in R&D. Besides, the 'Citrus price' is an effective factor to change producers' income and expected cost, so the second scenario seeks its behavior on the SD model. Moreover, 'Maximum Economic Yield' is another factor that has an interventionist role in the rate of production and productivity, so one scenario focuses on changes in this factor. On the other hand, variables' behavior over time can be affected by changes in 'Wage', so the fourth scenario is related to the worker wage. Moreover, the 'Local Manufacture Input' is considered another effective factor in this study. Also, the sixth and seventh scenarios are related to the 'Actual rainfall' and 'Solar radiation' as the environmental aspects of the model raised by climate change. Finally, scenario 8 seeks the behavior of Pesticides and fertilizers prices on the SD model. All of these scenarios are presented in Table 6. Also, it should be noted that all simulations are performed using the VENSIM DSS software.

R&D policy can increase total fresh fruit production and decrease greenhouse gas emissions. The mentioned emissions are caused by the consumption of fossil fuels for cultivating trees, transporting, and processing phases. To this end, the first scenario (Sim1) measures the investment in R&D using a STEP function. It will start at 900 (million Rial), remains constant till time 2018, and then jumps to 1350 (million Rials). Moreover, the formulation of the R&D policy is shown in Figure 12 and the effect of R&D on Yield Improvement is expressed as equations (68) to (70).

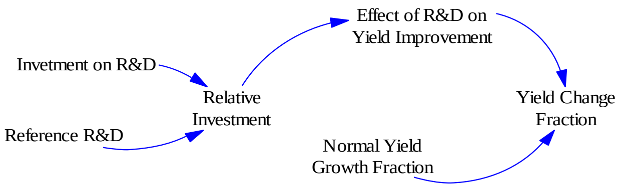


Fig 12. Formulation of R&D Policy

Table 6

Changes in parameter values after the policies applied to each scenario

Scenario counter	Action	Early value	Changed value
Sim1	Increase in investment on R&D (million Rials)	900	900+STEP (450, 2018)
Sim2	5% increase in Citrus price	Lookup	(1+0.05) Lookup
Sim3	10% increase in Maximum Economic Yield	18	19.8
Sim4	5% increase in Wage	1.6e+008	1.68e+008
Sim5	12% increase in Local Manufacture Input	256000	286720
Sim6	15% increase in Actual rainfall	300	345
Sim7	20% increase in Solar radiation	15	18
Sim8	5% increase in Pesticides and fertilizers price	Lookup	(1+0.05) Lookup

Yield Change Fraction = Normal Yield Growth Fraction × Effect of R&D on Yield Improvement (68)

Normal Yield Growth Fraction = 0.05 (69)

Effect of R&D on Yield Improvement = WITH LOOKUP (Relative Investment) (70)

(0.00, 0.60), (0.40, 0.65), (0.70, 0.75), (1.00, 1.00), (1.30, 1.45), (1.45, 2.00), (1.60, 2.50), (1.80, 2.80), (2.00, 3.00)

The Effect of R&D on Yield Improvement is important not only because it shows a non-linear relationship between Relative Investment and Yield Change Fraction. It is even more important because it changes the relative strength of the yield change loop. In this study, by applying changes in different scenarios, we will see the model behavior in the long run in Figures 13 to 18.

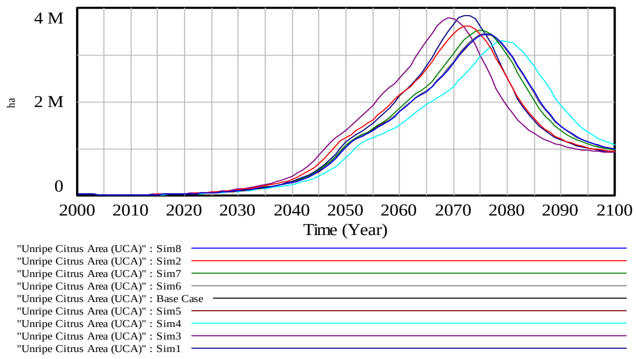


Fig 13. The simulation results for the unripe citrus area

Figure 13 shows that the unripe citrus area follows the overshoot and collapse behavior. So, in the base case and Sim6, the chart has positive growth up to the year 2076 and then the collapse occurs which in this year, the unripe citrus area grows up to about 3.5 million hectares, and then in 2100, it declines to 1 million hectares. The behaviors of other scenarios are also clear. For example, in 2050 the values of the base case, Sim1, Sim2, Sim3, Sim4, Sim5, Sim6, Sim7, and Sim8 are equal to 1.043 M, 1.14 M, 1.243 M, 1.398 M, 805900, 1.027 M, 1.043 M, 1.077 M, and 1.028 M, respectively.

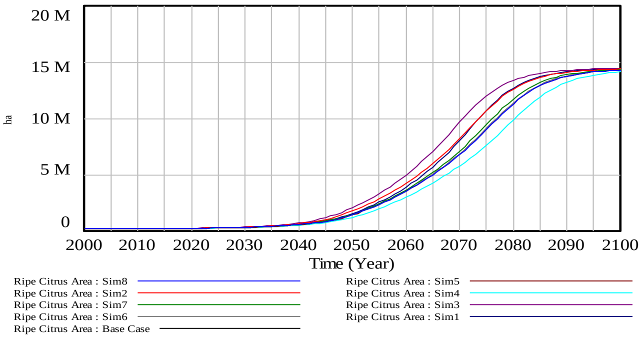


Fig 14. The simulation results for the ripe citrus area

Also, Figure 14 shows the simulation results of the ripe citrus area which follows the S-shape behavior. Therefore, in the base case and Sim6, the chart has positive growth up to the year 2095, and then it is fixed until 2100. Here ripe citrus area grows up to about 14.2 million hectares. The behaviors of other scenarios are also clear. For instance, in 2050 the values of the base case, Sim1, Sim2, Sim3, Sim4, Sim5, Sim6, Sim7, and Sim8 are equal to 1.441 M, 1.54 M, 1.772 M, 2.066 M, 1.189 M, 1.411 M, 1.441 M, 1.481 M, and 1.421 M, respectively. Simulation outcomes imply that Sim3 is superior to other scenarios shown in Figure 14 due to the impact of the Maximum Economic Yield on the ripe citrus area. On the other hand, Sim2 is the second important scenario that changes the base case to up and it implies that increasing citrus price can increase the ripe citrus area for obtaining more income. Furthermore, the Sim4 changes the base case to down and it is because increasing in Wage can decrease the ripe citrus area for obtaining less cost.

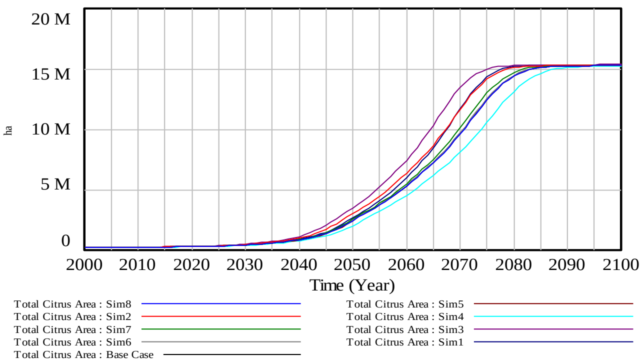


Fig 15. The simulation results for the total citrus area

Finally, the total citrus area is shown in Figure 15 which should indicate the sum of the unripe and ripe citrus area. Given that the value of the ripe citrus area is greater than the unripe citrus area, the S-shape behavior of the total citrus area is determined. Therefore, in the base case and Sim6, the chart has positive growth up to the year 2085, and then it is fixed until 2100. Here the total citrus area grows up to about 15 million hectares. The behaviors of other scenarios are also clear. For instance, in 2050 the values of the base case, Sim1, Sim2, Sim3, Sim4, Sim5, Sim6, Sim7, and Sim8 are equal to 2.484 M, 2.68 M, 3.015 M, 3.464 M, 1.994 M, 2.438 M, 2.484 M, 2.558 M, and 2.449 M, respectively. Simulation outcomes imply that Sim3 is superior to other scenarios shown in Figure 15 due to the impact of the Maximum Economic Yield on the ripe citrus area. On the other hand, Sim2 is the second important scenario that changes the base case to up and it implies that increasing citrus price can increase the total citrus area for obtaining more income. Furthermore, the Sim4 changes the base case to down and it is because increasing in Wage can decrease the total citrus area for obtaining less cost.

Furthermore, Figure 16 indicates the S-shape behavior of total fresh fruit production under eight scenarios. So, in the base case, the chart has positive growth and the amount of produced total fresh fruit is equal to 225 million tons in 2090. As is evident, in 2050 the values of the base case, Sim1, Sim2, Sim3, Sim4, Sim5, Sim6, Sim7, and Sim8 are equal to 22.46 M, 22.9 M, 21.6 M, 27.73 M, 19.67 M, 22.57 M, 22.46 M, 22.64 M, and 22.31 M, respectively.

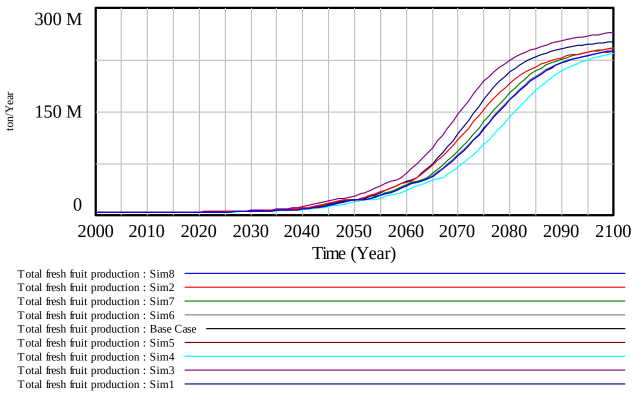


Fig 16. The simulation results for total fresh fruit production

Simulation results indicate that Sim3 is superior to other scenarios shown in Figure 16 due to the impact of the Maximum Economic Yield on the total fresh fruit production. On the other hand, Sim2 is the second important scenario that changes the base case to up and it indicates that increasing citrus price can increase the total fresh fruit production for obtaining more income. Furthermore, the Sim4 changes the base case to down and it is because increasing in Wage can decrease the total fresh fruit production for obtaining less cost.

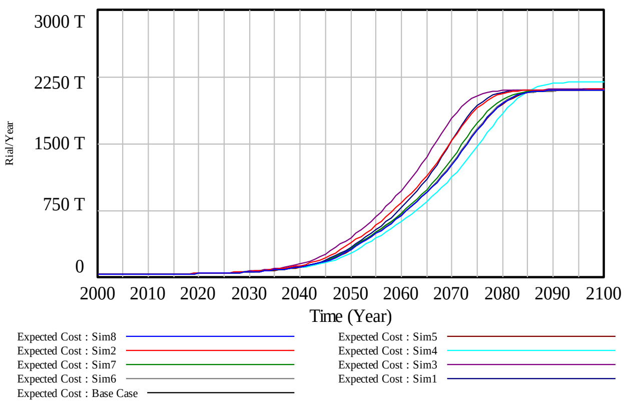


Fig 17. The simulation results for the expected cost

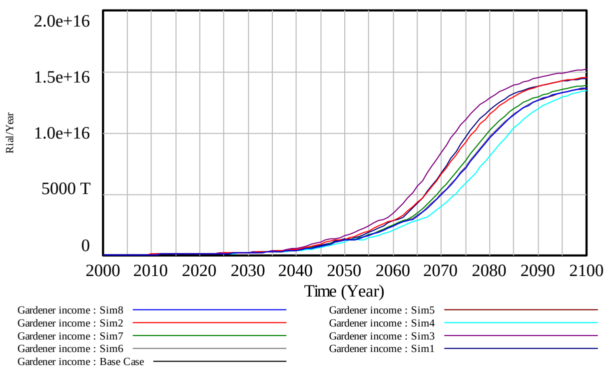


Fig 18. The simulation results for Producers' income

Furthermore, Figures 17 and 18 illustrate the economic aspects of this system dynamics model. Both of expected cost and Producers' income follow the S-shape behavior, however, there is a little difference in their performance under different scenarios. However, after 2085, increasing in Wage (Sim4) is more effective than other scenarios in raising the expected cost. For example, Figure 17 shows that the amount of expected cost in the base case is equal to about 1860 trillion Rial in 2100 and under Sim4 it reaches about 2050 trillion Rial. For instance, in 2050 the values of the base case, Sim1, Sim2, Sim3, Sim4, Sim5, Sim6, Sim7, and Sim8 for expected cost are equal to 314.9 T, 339.9 T, 387.7 T, 446.4 T, 266.4 T, 309.1 T, 314.9 T, 324.3 T, and 311.1 T, respectively.

Also, in 2050 the values of the base case, Sim1, Sim2, Sim3, Sim4, Sim5, Sim6, Sim7, and Sim8 for Producers income are equal to 1291 T, 1316 T, 1304 T, 1594 T, 1131 T, 1297 T, 1291 T, 1301 T, and 1283 T, respectively. Simulation results show that Sim3 is superior to other scenarios due to the impact of the Maximum Economic Yield on the expected cost and producers' income.

On the other hand, Sim1 and Sim2 are the second important scenarios that change the base case to up and it indicates that an increase in investment in R&D and citrus price can increase the expected cost and producers' income. Furthermore, the Sim4 changes the base case to down and it is because increasing in Wage can decrease the expected cost and producers' income. However, after 2085 increasing in Wage transfers the expected cost to upper than in other scenarios.

Therefore, changes in 'maximum economic yield', 'citrus price', and 'R&D policy' are found as three important and effective agents to achieve better performance than historical data. Therefore, these analyses and surveys can help managers of the agriculture sector and the implementation of these interventionist policies can lead to an increase in the profitability of producers and increased citrus production in the country.

4. Simplify modeling and Comparison

Although adding new parameters may bring the model closer to the real world, simpler models may have the same effectiveness, given the simplifying assumptions usually taken in SDs models. To this end, some simpler models are provided in this section and the comparison and sensitivity analysis with the proposed model are performed. Here, two simple models are presented in Figures (A.1) and (A.2). Based on simple model 1 illustrated in Figure (A.1), some factors such as follow are deleted.

- The R&D policy;
- Pruning effect, pruning of trees, the decision about pruning, pruning intensification rate, pruning delay, and normal pruning;
- Actual rainfall, rainfall, water held in the soil, evaporation rate, and potential evaporation.

Likewise, based on simple model 2 illustrated in Figure (A.2), some factors such as follow are deleted.

- The R&D policy;

- Pruning effect, pruning of trees, the decision about pruning, pruning intensification rate, pruning delay, and normal pruning;
- Actual rainfall, rainfall, water held in the soil, evaporation rate, and potential evaporation;
- Local manufacture input, domestic manufacture, pesticides and fertilizers' inventories, normal usage fraction, desired pesticides and fertilizers, transportation delay, pesticides and fertilizers' cost, pesticides and fertilizers price, pesticides and fertilizers' usage, the mismatch between supply and demand, and efficiency of using nutrition.

Based on Figure 10 the simulated values are verified using historical patterns. Using this figure, it was observed that the proposed model behavior is consistent with historical patterns. So, the results of the proposed model along with these two simple models are illustrated in Figure 19 to measure these two simple models' behaviors.

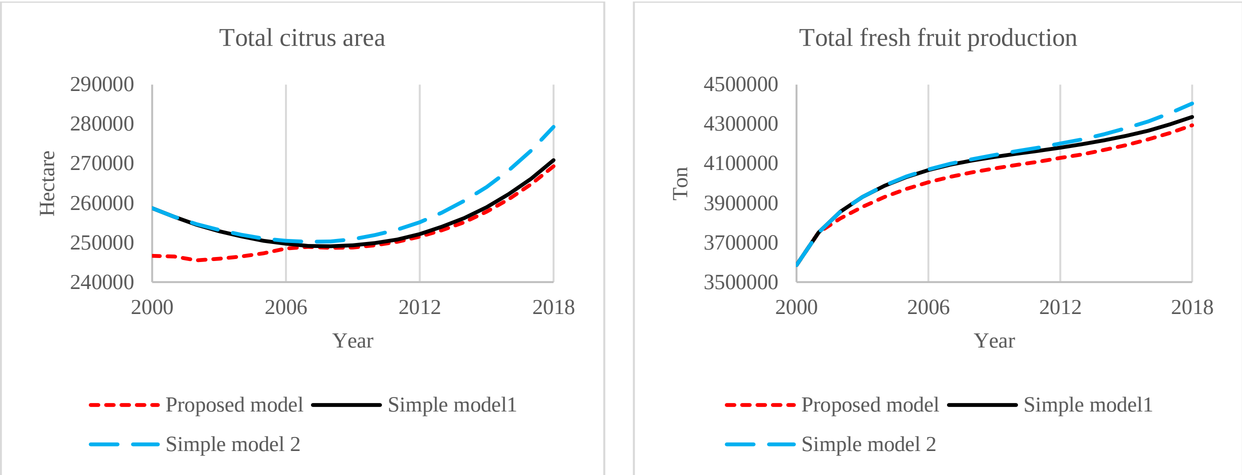


Fig 19. Comparison of simulation results of two simple models with the proposed model

The results of Figure 19 show that simplified models do not follow the trend of the proposed model, which was consistent with historical patterns. For example, this figure shows a significant gap in the 'total citrus area' between 2000 and 2006. From the years 2006 to 2018, although the behavior of the charts of the two simplified models is similar to the proposed model, there is still an obvious gap. Besides, for 'total fresh fruit production' although the behavior of the charts of the two simplified models is similar to the proposed model, there is an obvious gap. Therefore, it can be concluded that although simpler SDs models can be efficient, but in this case, they could not satisfy the problem.

5. Conclusion

In this study, a system dynamics model was developed for citrus production in which factors such as water shortage, solar effect, land use, and harvesting were considered as environmental aspects. Also, worker costs, the cost of fertilizers and pesticides, and the Producers' income were considered as economic aspects. The R&D policy, worker gaps, and the amount of product needed are also considered as social aspects. Finally, using the simulation of the proposed model, the impact of the relevant agents on citrus production was evaluated. Also, the robustness of the model has been verified by comparing simulation results with the historical data of the case study in Iran. Also, several statistical analyses were performed to prove the compliance of simulated model behavior with reality, which showed that the simulated model is consistent with historical patterns. To further study the Monte Carlo simulation for sensitive variables was performed, and the proposed model is finally implemented under different scenarios. Therefore, several interventionists such as R&D policies, citrus price, maximum economic yield, worker wage, local manufacturing input, actual rainfall, solar radiation, and pesticides and fertilizers' prices are considered effective factors in these scenarios. As observed, the unripe citrus area follows the overshoot and collapse behavior and the other mentioned variables include ripe citrus area, total citrus area, total fresh fruit production, expected cost, and Producers' income follow the S-shape behavior. Moreover, a 12% increase in local manufacturing input was practically ineffectual and was tended to the base case for all six variables. However, three key scenarios consisting of a 10% increase in maximum economic yield, an increase in investment in R&D, and a 5% increase in citrus price were very effective to move all graphs toward the left side. Therefore, changes in maximum economic yield, citrus price, and R&D policy were reported as three important and effective agents to achieve better performance than historical data. The performed analyzes can help agricultural managers and the application of these interventionist policies can lead to an increase in producers' income and citrus production in Iran. On the other hand, it should be noted that this research is geographically related to Iran and has been considered for its effective factors such as solar radiation, evaporation rate, amount of rainfall, and area under cultivation. Also, this study has been made only for sustainable citrus production in Iran. So, these assumptions are considered research limitations. It is also recommended for future research to consider the effectiveness and preparedness for pests and diseases and why separate treatments are necessary. Their different ability to respond to demand growth can also be demonstrated. As another factor, they can track the effect of changing demand forecasting functions across industries.

Declarations

Funding

The authors did not receive support from any organization for the submitted work.

Conflicts of interest

The authors have no relevant financial or non-financial interests to disclose.

References

Abebe, Y., Adey, B. T., & Tesfamariam, S. (2021). Sustainable funding strategies for stormwater infrastructure management: A system dynamics model. *Sustainable Cities and Society*, *64*, 102485. https://doi.org/10.1016/j.scs.2020.102485

Agriculture Jihad. (2016). *"Agricultural Letter Statistics", Department of Statistics and Information, Deputy of Planning and Support, Ministry of Agriculture Jihad*. Tehran. Retrieved from https://www.maj.ir/

Antle, J. M., & Stoorvogel, J. J. (2006). Incorporating systems dynamics and spatial heterogeneity in integrated assessment of agricultural production systems. *Environment and Development Economics*, *11*(1), 39–58. https://doi.org/10.1017/S1355770X05002639

Bala, B. K., Arshad, F. M., & Noh, K. M. (2017). Systems Thinking: System Dynamics (pp. 15–35). https://doi.org/10.1007/978-981-10-2045-2_2

Chapman, A., & Darby, S. (2016). Evaluating sustainable adaptation strategies for vulnerable mega-deltas using system dynamics modelling: Rice agriculture in the Mekong Delta's An Giang Province, Vietnam. *Science of The Total Environment*, *559*, 326–338. https://doi.org/10.1016/j.scitotenv.2016.02.162

Cheraghalipour, A., Paydar, M. M., & Hajiaghaei-Keshteli, M. (2018). A Bi-objective Optimization for Citrus Closed-Loop Supply Chain Using Pareto-Based Algorithms. *Applied Soft Computing*, *69*, 33–59. https://doi.org/10.1016/j.asoc.2018.04.022

Cheraghalipour, A., Paydar, M. M., & Hajiaghaei-Keshteli, M. (2019). Designing and solving a bi-level model for rice supply chain using the evolutionary algorithms. *Computers and Electronics in Agriculture*, *162*, 651–668. https://doi.org/10.1016/j.compag.2019.04.041

Dace, E., Muizniece, I., Blumberga, A., & Kaczala, F. (2015). Searching for solutions to mitigate greenhouse gas emissions by agricultural policy decisions — Application of system dynamics modeling for the case of Latvia. *Science of The Total Environment*, *527–528*, 80–90. https://doi.org/10.1016/j.scitotenv.2015.04.088

Etemadnia, H., Goetz, S. J., Canning, P., & Tavallali, M. S. (2015). Optimal wholesale facilities location within the fruit and vegetables supply chain with bimodal transportation options: An LP-MIP heuristic approach. *European Journal of Operational Research*, *244*(2), 648–661. https://doi.org/10.1016/j.ejor.2015.01.044

FAO. (2017). *Citrus Fruit Fresh and Processed Statistical Bulletin 2016*. *Food and Agriculture Organization of the United Nations*. Retrieved from http://www.fao.org/3/a-i8092e.pdf

Huang, H., Chen, Y., Clinton, N., Wang, J., Wang, X., Liu, C., … Zhu, Z. (2017). Mapping major land cover dynamics in Beijing using all Landsat images in Google Earth Engine. *Remote Sensing of Environment*, *202*, 166–176. https://doi.org/10.1016/j.rse.2017.02.021

Hosseini, S., & Paydar, M. (2022). Examining and Prioritizing the Factors Affecting Tourist Absorption for Ecotourism Centers Utilizing MCDM Tools. *Journal of Optimization in Industrial Engineering*, 15(1), 17-30. doi: 10.22094/joie.2021.1924575.1831

Ibragimov, A., Sidique, S. F., & Tey, Y. S. (2019). Productivity for sustainable growth in Malaysian oil palm production: A system dynamics modeling approach. *Journal of Cleaner Production*, *213*, 1051–1062. https://doi.org/10.1016/j.jclepro.2018.12.113

Jampani, M., Amerasinghe, P., Liedl, R., Locher-Krause, K., & Hülsmann, S. (2020). Multi-functionality and land use dynamics in a peri-urban environment influenced by wastewater irrigation. *Sustainable Cities and Society*, *62*, 102305. https://doi.org/10.1016/j.scs.2020.102305

Kopainsky, B., Hager, G., Herrera, H., & Nyanga, P. H. (2017). Transforming food systems at local levels: Using participatory system dynamics in an interactive manner to refine small-scale farmers' mental models. *Ecological Modelling*, *362*, 101–110. https://doi.org/10.1016/j.ecolmodel.2017.08.010

Kotir, J. H., Smith, C., Brown, G., Marshall, N., & Johnstone, R. (2016). A system dynamics simulation model for sustainable water resources management and agricultural development in the Volta River Basin, Ghana. *Science of The Total Environment*, *573*, 444–457. https://doi.org/10.1016/j.scitotenv.2016.08.081

Li, F. J., Dong, S. C., & Li, F. (2012). A system dynamics model for analyzing the eco-agriculture system with policy recommendations. *Ecological Modelling*, *227*, 34–45. https://doi.org/10.1016/j.ecolmodel.2011.12.005

Martínez-Jaramillo, J. E., Arango-Aramburo, S., & Giraldo-Ramírez, D. P. (2019). The effects of biofuels on food security: A system dynamics approach for the Colombian case. *Sustainable Energy Technologies and Assessments*, *34*, 97–109. https://doi.org/10.1016/j.seta.2019.05.009

Ministry of Agriculture-Jahad of Iran. (n.d.). Retrieved from https://www.maj.ir/index.aspx?lang=2&sub=0

Moein, M., Asgarian, A., Sakieh, Y., & Soffianian, A. (2018). Scenario-based analysis of land-use competition in central Iran: Finding the trade-off between urban growth patterns and agricultural productivity. *Sustainable Cities and Society*, *39*, 557–567. https://doi.org/10.1016/j.scs.2018.03.014

Mohammadi, S., Arshad, F. M., Bala, B. K., & Ibragimov, A. (2015). System Dynamics Analysis of the Determinants of the Malaysian Palm Oil Price. *American Journal of Applied Sciences*, *12*(5), 355–362. https://doi.org/10.3844/ajassp.2015.355.362

Pluchinotta, I., Pagano, A., Giordano, R., & Tsoukiàs, A. (2018). A system dynamics model for supporting decision-makers in irrigation water management. *Journal of Environmental Management*, *223*, 815–824. https://doi.org/10.1016/j.jenvman.2018.06.083

Pluchinotta, I., Pagano, A., Vilcan, T., Ahilan, S., Kapetas, L., Maskrey, S., … O'Donnell, E. (2021). A participatory system dynamics model to investigate sustainable urban water management in Ebbsfleet Garden City. *Sustainable Cities and Society*, *67*, 102709. https://doi.org/10.1016/j.scs.2021.102709

Rich, K. M., Rich, M., & Dizyee, K. (2018). Participatory systems approaches for urban and peri-urban agriculture planning: The role of system dynamics and spatial group model building. *Agricultural Systems*, *160*, 110–123. https://doi.org/10.1016/j.agsy.2016.09.022

Rozman, Č., Pažek, K., Kljajić, M., Bavec, M., Turk, J., Bavec, F., … Škraba, A. (2013). The dynamic simulation of organic farming development scenarios – A case study in Slovenia. *Computers and Electronics in Agriculture*, *96*, 163–172. https://doi.org/10.1016/j.compag.2013.05.005

Rozman, C., S□kraba, A., Kljajić, M., Paz□ek, K., Bavec, M., Bavec, F., & Dubois, D. M. (2008). The System Dynamics Model for Development of Organic Agriculture. In *AIP Conference Proceedings* (pp. 380–389). AIP. https://doi.org/10.1063/1.3020677

Saavedra M., M. R., de O. Fontes, C. H., & M. Freires, F. G. (2018). Sustainable and renewable energy supply chain: A system dynamics overview. *Renewable and Sustainable Energy Reviews*, *82*, 247–259. https://doi.org/10.1016/j.rser.2017.09.033

Saeidi Aghdam, M., Alamtabriz, A., Sarafizadeh Qazvini, A., & Zandhessami, H. (2020). A system Dynamics Approach to Designing a Crowdfunding Model in Technological Entrepreneurship Ecosystem with a Focus on Technology Incubator Centers. J*ournal of Optimization in Industrial Engineering*, 13(1), 113-122.

Saysel, A. K., Barlas, Y., & Yenigün, O. (2002). Environmental sustainability in an agricultural development project: a system dynamics approach. *Journal of Environmental Management*, *64*(3), 247–260. https://doi.org/10.1006/jema.2001.0488

Sayyadi tooranloo, H., Karimi Takalo, S., & Mohyadini, F. (2022). Analysis of Causal Relationships Effective Factors on the Green Supplier Selection in Health Centers Using the Intuitionistic Fuzzy Cognitive Map (IFCM) Method. *Journal of Optimization in Industrial Engineering*, 15(1), 93-108.

Senge, P. M., & Forrester, J. W. (1980). Tests for building confidence in system dynamics models. *System Dynamics, TIMS Studies in Management Sciences*, *14*, 209–228.

Shi, T., & Gill, R. (2005). Developing effective policies for the sustainable development of ecological agriculture in China: the case study of Jinshan County with a systems dynamics model. *Ecological Economics*, *53*(2), 223–246. https://doi.org/10.1016/j.ecolecon.2004.08.006

Sterman, J. D. (1994). Learning in and about complex systems. *System Dynamics Review*, *10*(2–3), 291–330. https://doi.org/10.1002/sdr.4260100214

Sterman, J. D. (2000). *Business dynamics: systems thinking and modeling for a complex world*. Boston: McGraw-Hill Education.

Teimoury, E., Nedaei, H., Ansari, S., & Sabbaghi, M. (2013). A multi-objective analysis for import quota policy making in a perishable fruit and vegetable supply chain: A system dynamics approach. *Computers and Electronics in Agriculture*, *93*, 37–45. https://doi.org/10.1016/j.compag.2013.01.010

Walters, J. P., Archer, D. W., Sassenrath, G. F., Hendrickson, J. R., Hanson, J. D., Halloran, J. M., … Alarcon, V. J. (2016). Exploring agricultural production systems and their fundamental components with system dynamics modelling. *Ecological Modelling*, *333*, 51–65. https://doi.org/10.1016/j.ecolmodel.2016.04.015

Wei, S., Yang, H., Song, J., Abbaspour, K. C., & Xu, Z. (2012). System dynamics simulation model for assessing socio-economic impacts of different levels of environmental flow allocation in the Weihe River Basin, China. *European Journal of Operational Research*, *221*(1), 248–262. https://doi.org/10.1016/j.ejor.2012.03.014

Young, J. (n.d.). Lifespan of Citrus Trees. Retrieved from https://www.gardenguides.com/12494745-lifespan-of-citrus-trees.html

Zabel, F., Putzenlechner, B., & Mauser, W. (2014). Global Agricultural Land Resources – A High Resolution Suitability Evaluation and Its Perspectives until 2100 under Climate Change Conditions. *PLoS ONE*, *9*(9), e107522. https://doi.org/10.1371/journal.pone.0107522

Appendix (A): The stock-and-flow diagram of two simple model 1 and 2

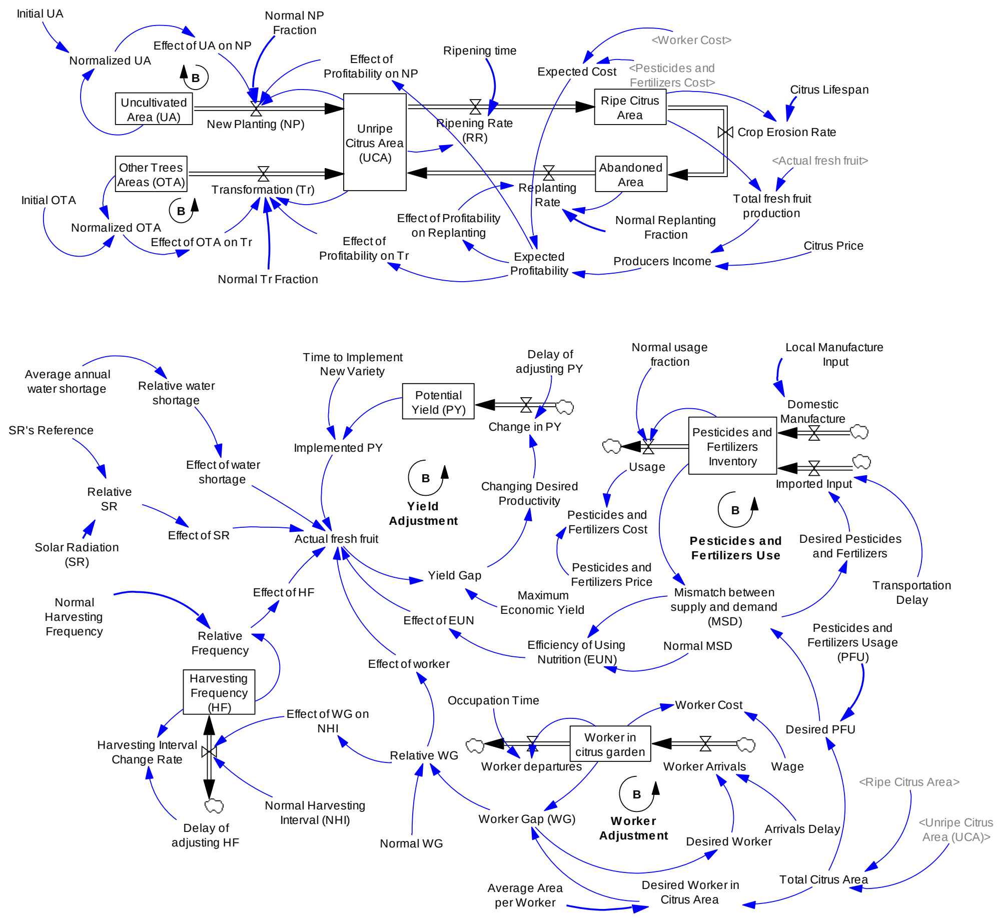


Fig (A1). The stock-and-flow diagram of simple model 1

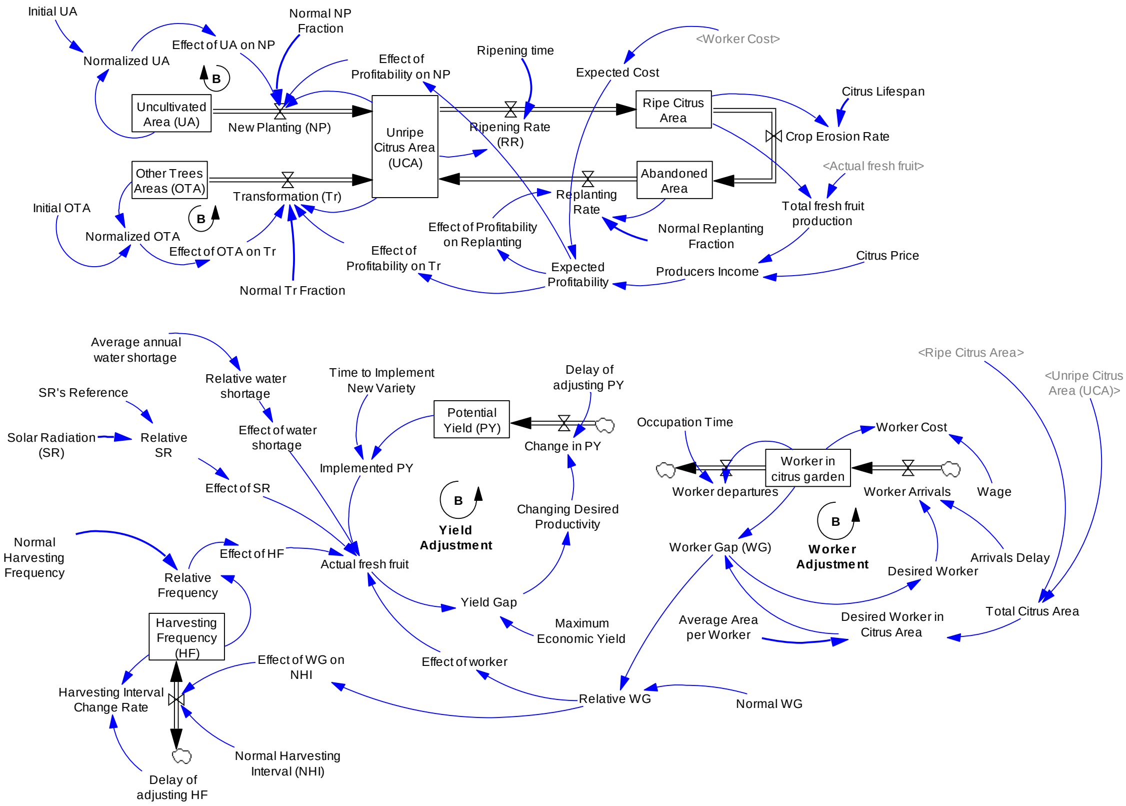


Fig (A2). The stock-and-flow diagram of simple model 2

This article can be cited: Cheraghalipour, A., & Roghanian, E. (2022). Assessing the Impact of Environmental Aspects, Land Use, and R&D Policies on Peri-Urban Agriculture Using a System Dynamics Approach. *Journal of Optimization in Industrial Engineering*, *15*(2), 147-165. Doi: 10.22094/joie.2022.1946966.1923