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Regional Modeling for Optimal Allocation of Agricultural Crops Considering Environmental Impacts, Housing Value and Leisure Preferences

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ABSTRACT

Regional planning should consider the impact of agricultural crops on housing value and leisure, as well as on the local environment. We designed an optimization model for allocating agricultural crops based on farmers profits as well as the impact on these three factors. Each crop creates a different landscape, as well as a different effect on shading and noise reduction. These in turn influence the value of nearby housing and the regional leisure opportunities. Each crop also has a positive and negative environmental impact, including potential use of treated wastewater as well as the effects of pesticides and fertilizers. All these factors were combined with economic considerations to suggest the optimal regional allocation of agricultural crops.

Keywords: open spaces, housing, economics, environment, agriculture, crops

JEL codes: Q18, Q51, R13, R14, R21

1. Introduction

Regional planning for sustainable development should consider the impact of agricultural crops on the environment, economics and social aspects.

Agricultural production influences many different aspects of the environment (Spharim and Haruvy, 1999; Shalhevet et al., 2001, 2002). These include the use of pesticides and fertilizers, which affect the quality of the soil, groundwater and air, and in the case of persistent pollutants the effect can last for generations. Another aspect includes the influence on natural resources such as biodiversity. Agricultural production also influences sustainability through use of freshwater resources and CO_2 emissions or sequestration.

Agricultural production also has an economic influence on different segments of the population. The most obvious one is the influence on the farmers' income and the income of food product manufacturers and retailers. Agricultural crops also influence income from tourism, both directly through agricultural tourism and indirectly through the increase in tourists in areas with open cultivated spaces (Fleischer and Tsur, 1999). Plants have also been shown to have a significant impact on the value of housing and on the retailers income in areas with trees and open spaces.

The influence of agricultural crops on social welfare includes the social value of open spaces. It was found that people attribute a value to the existence of open spaces even when they do not visit the area themselves. Different crops have a different influence on the enjoyment of scenery and leisure in the region. Other social welfare impacts include the impact on noise reduction and shading and temperature reduction in the neighborhood.

The farmer aims to maximize his profits from agricultural production. However, optimized planning from the societal viewpoint requires taking into account the total impact on public welfare, including the environmental, social and economic aspects. The impact of agricultural crops on total welfare is usually much higher than the impact on the farmers' profit alone.

In order to compare the different impacts of each crop in an optimization model, each impact of each crop should be evaluated. Methods of quantifying the environmental impact in economic terms are described in previous publications (Haruvy, 1997; Haruvy, 1998; Haruvy et al., 1999, 2004). Hedonic pricing expresses the influence on property value of scenery and other regional amenities; and willingness to pay questionnaires can estimate the welfare value of natural systems (Fleischer and Tsur, 1999). Negative environmental impacts can be measured by the cost of prevention or mitigation of the damage.

2. Methodology

We defined an optimization model with two alternative target functions. The first target function is maximization of the total profits of the farmers in the region. The second is maximization of the total welfare to society; the borders of society were defined using different areas of influence: impact on the regional population and on the national population. The changing variables are the agricultural crops that are currently grown in the region. The output of the model is the optimal combination of agricultural crops.

The model was implemented on the area of Regional Council Emek Heffer as a representative case. About 30,000 residents live there, mostly in kibbutzim and in agricultural settlements. The cultivated crop area is about 7.5 thousand hectares, at a total annual value of $157,560 – about a quarter of the total value of regional production. The crops are mostly field crops (51% of total area) and citrus (28%).

The crops used in the model cover approximately 60 percent of the cultivated area in the region, and include several field crops, vegetables, flowers, citrus and other orchards. The economic value of the impacts was estimated by adapting economic values from existing literature, questionnaires filled by experts on the environment, agriculture and public policy.

The following categories of impacts were evaluated:

- Environmental impacts: the impact on the environment, natural resources and sustainability included the impacts of fertilizers, pesticides, CO_2 emissions and carbon sequestration on the air and groundwater resources.
- Economic impacts: the impact on regional economics includes the income to farmers and the impact of scenery on local housing value.
- Social impacts: this included the recreational value of the scenery on the tourist and local population, as well as the value of noise reduction and temperature reduction. High levels of noise can cause severe hearing damage (LaMuth, 1998), and the noise reduction provided by plants can have health aspects as well.

Environmental impacts

Pesticides and fertilizers: For pesticides and fertilizers, we examined the cost of remediation – removal of chemicals after they have infiltrated the groundwater. Data on pesticide and fertilizer use for each crop was taken from local crop budgets, and the economic value from previous research such as Pretty (2000), Haruvy et al. (1999) and Haruvy et al. (2000).

Carbon emissions or sequestration: The economic impact of CO2 is usually measured using abatement cost curves (Schneider, 2002). For CO_2, we used carbon sequestration or emissions caused by growing different crops and the willingness to pay to prevent it. We used existing data on CO2 emissions by crop in Emek Heffer (Freeman, 2001) and economic evaluations such as Hoen (1994).

Another important impact which was not included in the model is the impact on landfill waste. Research on Emek Heffer's waste by acre of crops showed that citrus is the largest source of landfill waste per acre grown (Freeman, 2001).

Economic impacts

The effect on the farmers' income was calculated using crop budgets published by the Israeli Extension Service. The impact on the housing market was calculated based on scenery preferences for different crops and existing research on the impact of scenery on housing value. The scenery preferences were adapted from existing research (for example, Misgav, 2000; Herzon, 2000; Scrinzi and Floris 2000). The influence of the scenery provided by each crop on the nearby houses was calculated based on relative preferences for different views (open field with low or high field crops, trees with different shapes, etc.) and their influence on housing value. The premium (in percentage of housing value) by different type of scenery was adapted from sources such as Luttik (2000), and adjusted to local housing prices.

Social Impacts

The recreational value of agricultural crops was estimated by Fleischer and Tsur (1999). Because this value also increases the income from tourism to the area, it was included under "economic impacts" as the out-of-area value of scenery.

The degree of noise reduction was evaluated using research on the impact of different types of plants on noise levels in decibels (Schiller et al., 2000) and the influence of noise reduction by 1 decibel on the value of nearby housing. This measure overlaps to some degree with the previous impact category of housing value, but is included in this category because of the important health implications of noise reduction.

The degree of temperature reduction was evaluated using research on the impact of different types of plants on temperatures in their surroundings (Schiller, 1998). The economic value was measured using surveys on willingness to pay for temperature changes (Moore, 1998).

Areas of influence

We divided the system into different areas of influence. The local area includes the residents of Emek Heffer; the regional area includes the nearby urban areas as well; and the national area includes the entire population of Israel. As the area of influence becomes larger, the size of the population exposed to the potential impacts increases, but the importance of each impact changes. The impacts of noise, temperature and scenery at the local area decrease as the distance from the crop area increases. However, the environmental impacts increase as the population exposed increases at larger areas of influence. We conducted a survey of experts in order to estimate the importance of each potential impact on the different areas. The expert ratings were used as input to the model.

3. Results

Areas of influence

Based on the results of our survey, each impact was assigned a relative ranking from 0 to 1 (maximum impact), varied by the area of influence. The results are presented in Table 1. The social and economic impacts are highest (a value of 1) at the local area. The social impact of noise and temperature reduction are relevant mainly for the people who live near the agricultural field. For scenery, the impact on housing value is high when the scenery can be viewed from the house, and is reduced as people move further away. At the national area, the benefit of the scenery is for recreational purposes and as existence value, which is actually a social impact, and its economic value is lower. The importance of the environmental impacts increase as the population exposed becomes larger at larger areas of influence. Therefore, these impacts have a high ranking at the national area, but a low ranking at the local area, where the number of people exposed to the damage is small.

Table 1: The importance of each impact by area of influence

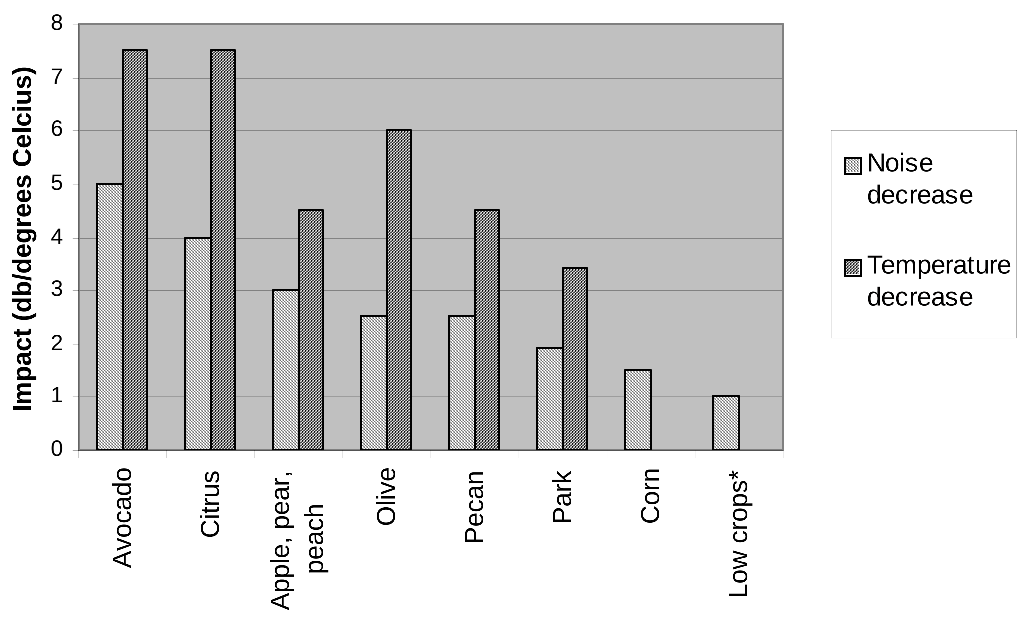
Impact / Influence area	Local	Regional	General Regional	National
Population. (‘000)	30	250	280	6,000
Social impact: noise & temp.	1.000	0.100	0.196	0.00
Economic: housing & tourism	1.000	0.750	0.777	0.25
Environment: pesticides, fertilizers & CO_2	0.005	0.042	0.038	1.00

Estimation of influence

Social Impacts

Noise: Based on existing research (Schiller et al., 2000), the effectiveness of each plant in noise reduction was rated (Figure 1). The effectiveness ranged between a noise reduction of 1 decibel in vegetables to 5 decibels in avocado. Trees that are densely planted and have larger and thicker leaves have the highest value; therefore avocado is more effective than pecans, for example, in noise reduction. Parks are less effective because the trees are more sparsely planted than in orchards. Taller field crops, such as corn, are more effective than low field crops. The economic value of the noise reduction was calculated based on the influence on the values of the houses in the area, which is about 0.5% lower value for an increase of 1 decibel in the noise level.

Figure 1. Social Impacts by Crop



* Vegetables, field-crops, flowers

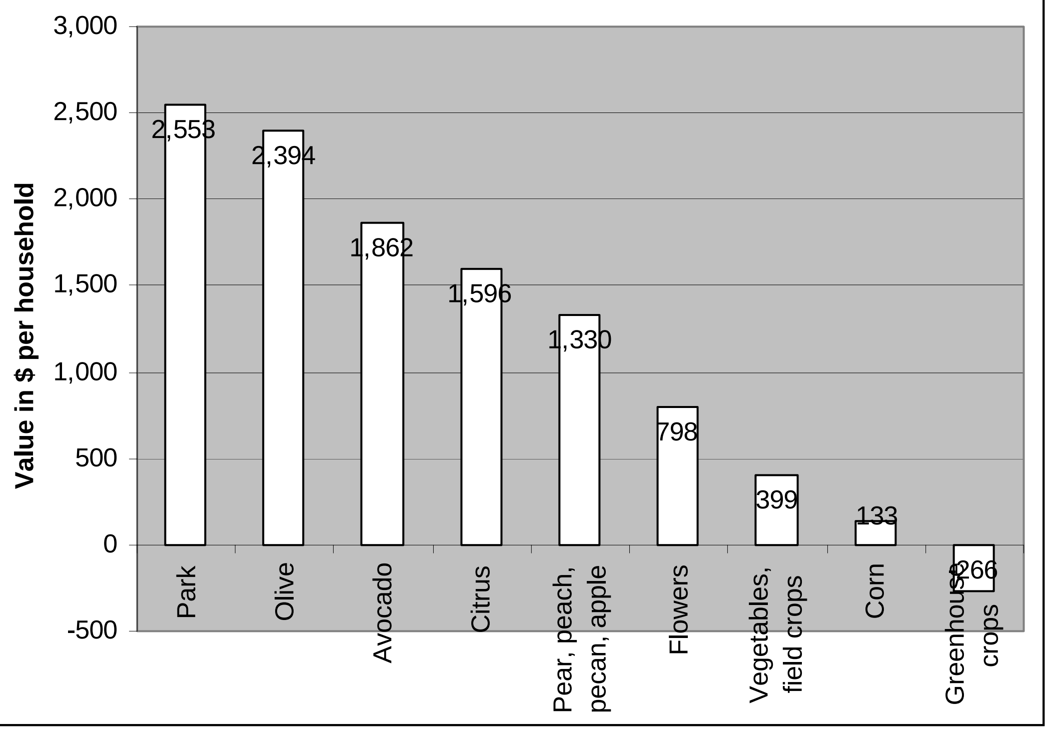
Temperature: Based on existing research (Schiller, 1998), the effectiveness of each plant in shading and temperature reduction was rated (Figure 1). The effectiveness ranged between 0 degrees Celsius in vegetables to 7.5 degrees in avocado and citrus. Trees have varying levels of effectiveness, depending on the tree structure, while low-growing crops do not have an effect on the temperature as compared with other non-paved land use options. However, if we had compared crops with a paved alternative, such as asphalt, than even low-growing crops would have had a positive effect of temperature reduction. The economic value of a change of 1 degree Celsius was calculated based on existing research on valuation of temperature change.

Impact on the housing markets

According to existing surveys, people prefer trees than are tall, have a spreading round shape rather than conic shape, have local cultural connotations (such as the olive trees in Israel), and are planted in low and medium density. Based on scenery preferences and research on the effect of scenery types on housing prices, we calculated the effect of the scenery provided by each crop on the average price of nearby houses (Figure 2). Nearby trees increase the value of the housing more than field crops and vegetables do, and greenhouses detract from the value of the house.

The leisure value of agricultural crops, as found in a survey conducted by Fleischer and Tsur (1999), is similar to the effect on housing value.

Figure 2. Impact of scenery on housing value



Environmental Impacts

The environmental impacts by crop are summarized in Table 2, in kilograms per hectare, based on Freeman (2001). CO_2 emissions from growing greenhouse crops are around 30,000 kilogram per hectare, which is more than ten-fold the amount of emissions caused by growing other crops. Field crops, especially wheat, cause the least amount of emissions. Pesticide use is highest in growing flowers in greenhouse, followed by tomatoes. Orchards and field crops require lower amounts of pesticides. The effect of fertilizer use is measured by the amount of nitrogen leaking into the groundwater; the economic cost of remediation was then calculated according to the cost of restoring the groundwater to drinking water quality. Citrus growing causes the greatest amount of nitrogen leakage, while greenhouse crops cause about half of that amount of leakage. Field crops for silage are grown without fertilizers and therefore are not associated with nitrogen leakage to groundwater. There is a high correlation between pesticide use and CO_2 emissions (0.75), but no correlation between CO_2 emissions and fertilizer use.

Table 2: Environmental effects (CO_2 emissions, pesticide usage, and nitrogen leakage from fertilizer use), in kilograms per hectare.

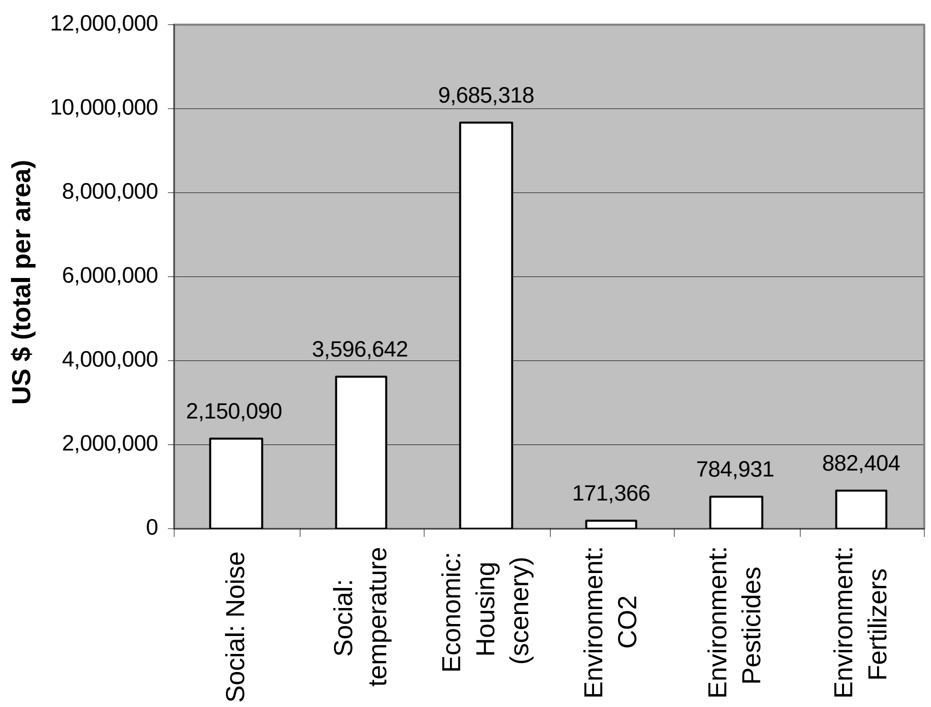
Crop	CO2 emissions	Pesticide usage	Nitrogen leakage
Avocado	2,470	NA	276
Pecan	1,270	81	47
Shamouti oranges	940	129	293
Gypsophilia in a greenhouse	28,380	1,518	127
Tomatoes in a greenhouse	32,550	547	140
Tomatoes in open space	1,200	619	31
Cotton	190	23	230
Corn	160	6	192
Alfalfa	160	11	0
Wheat for silage	50	NA	0

Source: Freeman, 2001

Economic valuation of the impacts

The economic value of each impact, for the existing crop allocation, is shown in Figure 3. For the social impacts (noise and temperature reduction) and the housing market, this shows the total value for the local area of influence, who are the main beneficiaries of this impact. For the environmental impacts, this shows the value for the national area of influence, as the entire country is affected be reduced water quality in the aquifer or increased emissions. The total social and housing value benefits for the Emek Heffer area are 15.4 million dollars, and 63 percent of this value is accounted for by the increase in housing value due to the agricultural scenery. The negative value of the environmental impact on Israel is 1.8 million dollars.

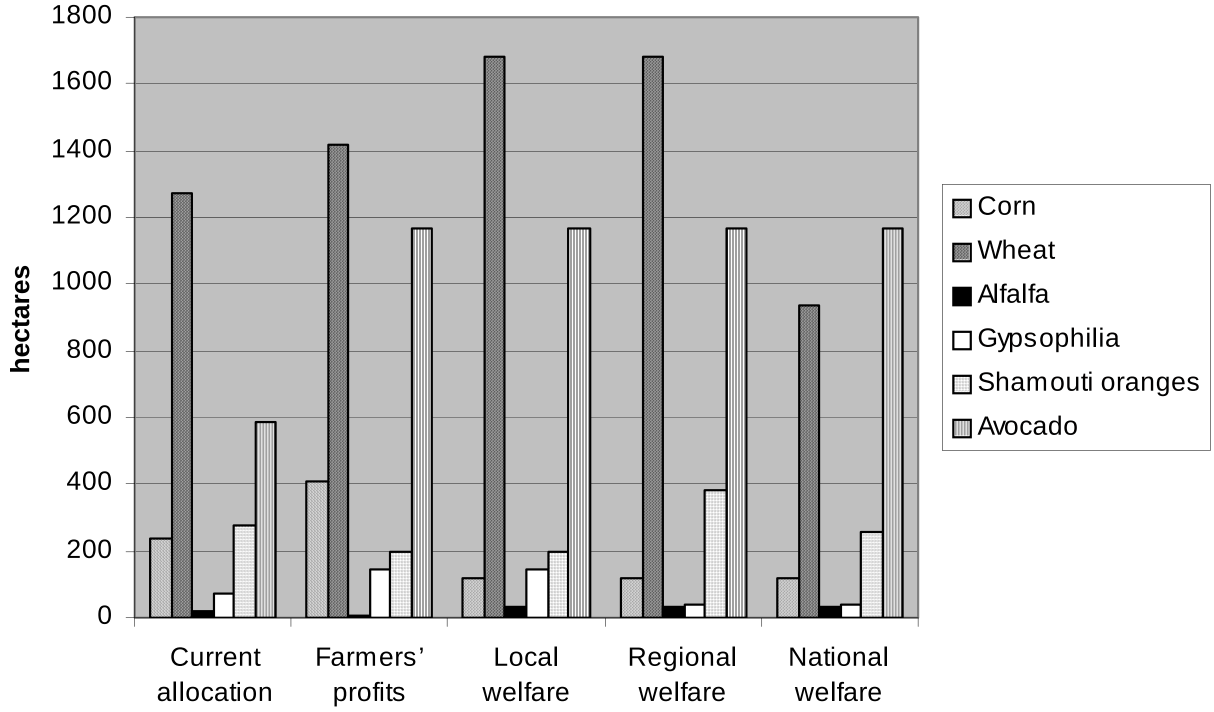
Figure 3: Economic value by impact



Results of optimization model

The optimization model considered the economic value of each impact for each crop. The results of the optimization model show the optimal crop allocation in the region. These results were examined for different target functions, varying by area of influence. The first target function was maximizing the profits for farmers. The second was maximizing the profits and the socio-economic and environmental impacts on the local area. The third function expanded this to include the impacts on the entire region, and the fourth function looked at total profits and impacts for the country. The results for a representative selection of the crops is shown in Figure 4. These results are compared with the current allocation, where each farmer considers his own profit, rather than the total farmers' profits in the optimization model.

Figure 4. Crop area in hectares under different target functions



The results of the optimization model show that the avocado area should be doubled under all target functions, because of it high scenic and social impact values as well as profitability. The optimal area for oranges is 72% of the current area for the farmers and local target functions, because of its relatively low profitability. The area is increased by 38% over the current allocation when the regional benefits are considered, because of its high scenic value for the region; it is then slightly decreased from the current allocation for the national target function, because oranges are the highest consumers per acre of fertilizers.

The optimal area for flowers in greenhouses (Gypsophilia) is double the current allocation under the farmers and local target functions because of its high profitability. The optimal area is half the current allocation under the regional and national target functions because of its negative scenic value and high levels of pesticide use and CO_2 emissions.

Regarding field crops, the optimal area for corn is 70 percent larger than the current allocation under the farmers profits target function, because of its high profitability. The optimal area is half of the current allocation under all other target functions, because of its low scenic value compared with other field crops and high fertilizer use. The optimal area for wheat under the farmers profits function is 11% higher than the current allocation, and 32% higher under the local and regional target functions, but is then reduced to 73% of the current allocation under the national target function. In contrast, the optimal area of alfalfa in order to maximize the farmers profits is about half of the current allocation, but is nearly doubled under all other target functions because of its low environmental impacts compared with other field crops, while its scenic and social contributions are the same as other field crops.

The optimization model shows that if the farmers organized to maximize their total profits, they could increase the total farmers profits for the region by 5.5 million dollars, while increasing the social and housing value by 8.2 million dollars and reducing the cost of the environmental impacts by 2.6 million dollars. However, if the crop allocation was planned in order to maximize the national benefits, the farmers would lose 16.8 million dollars (turning regional farming, in effect, into a losing enterprise). In that case the social and housing value would increase by 674 million dollars and reducing the cost of the environmental impacts by 690 million dollars. Planning an optimal regional allocation would enable the farmers to increase their income by 1.7 million dollars over the current allocation, while the value of the social impacts and housing value would increase by 90 million dollars and the cost of the environmental damage would decrease by 88.3 million dollars.

4. Conclusions

The decision on the optimal crop allocation depends on the target function chosen. It is possible to change the allocation so that the total farmers income in the region is increased, while increasing the value of the social impacts and the housing value, and reducing the environmental impacts. However, there is a tradeoff – the more we plan to increase the farmers profits, the less we can increase the value of the other impacts. An optimization for the entire country would entail turning farming from profit to loss; however, this might be considered in order to increase the social impacts and housing value, and the beneficiaries might pay the farmers to compensate for the loss.

The main impact, in economic terms, is the impact on the housing value in the region as function of the scenery provided by the different crops. This is significant in the Emek Heffer region, which has large cultivated areas. Optimal planning would entail switching to orchard crops with high scenic and social value, such as avocado, at the expense of other orchards; and switching from high-growing field crops such as corn to low-growing crops such as wheat. Despite the high economic value of greenhouse crops, their area should be decreased because of their negative scenic and environmental impacts.

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