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An Assessment of the Sustainability of Agricultural Systems in Golestan Province, Iran

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Abstract

Sustainable agriculture is a holistic approach to produce food, fiber, feed and fuel in a way that does not damage the environment and also must meet the needs of the present and future population of the world, while considering agro-ecosystem health, social and economic equity and profitability. Therefore, the sustainable agriculture cannot be isolated from the concept of sustainable development in any country or region. The current survey was conducted in order to study the sustainability of agricultural systems in Golestan Province in the north of Iran during the period of 2002-2011. The required data were obtained from formal statistical database. The total numerical value of sustainability was calculated for individual years using 21 different indexes. Because of the diverse nature of the selected indexes and their wide range, they were normalized to facilitate their comparison. The results show that the agricultural sustainability has been increased significantly over the studied period. The lowest value of sustainability was observed in the first year of the studied period (i.e., 2002) but the highest value was calculated for 2009 and thereafter the sustainability of agro-ecosystem has decreased slightly. The improvement of sustainability could be attributed to the application of less chemical inputs such as pesticides and fertilizers, higher water and nitrogen use efficiencies, higher yield of different crops, especially dry land crops and the higher cultivation area of nitrogen fixing species.

Keywords:
agro-ecosystem, chemical inputs, crop yield, water use efficiency

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INTRODUCTION

Although industrial agriculture has increased food production in a faster pace than the population growth over the last century, there are concerns that the existing methods of modern agriculture are unsustainable due to high consumption rate of energy and chemical inputs (Wezel et al., 2014). The adoption of the industrial agriculture methods has resulted in a series of negative environmental effects such as contamination of surface drainage and groundwater with pesticide and highly soluble chemical fertilizers, soil compaction by excessive use of machinery, reduction in biodiversity, overexploitation of natural resources, and high rates of carbon emission due to direct or indirect consumption of petroleum. In arid regions, irrigation requirement, alongside inputs of chemical fertilizer, pesticide and machinery, has been identified with a range of further negative environmental impacts, including depleted groundwater and soil salinization where drainage is inadequate (Mollinga, 2010).

Nowadays, the expansion of agricultural lands and the intensification of production methods have already reached their socioeconomic and environmental thresholds in different parts of the world, especially in developed countries. Therefore, sustainable agriculture with its holistic principles has a key role in finding the solutions for these challenges. The correct management of soil, water and fertilizer is critical for sustainable agriculture because such management can flourish food production and enhance the quality of environment (Drechsel et al., 2015).

Sustainable agriculture emphasizes agricultural methods and technologies which (i) do not have negative effects on the environment, (ii) are effective and accessible for farmers, and (iii) both improves food productivity and positively influences environmental goods and services. Therefore, sustainability in agricultural systems incorporates concepts of both resilience (the capacity of systems to buffer shocks and stresses) and persistence (the capacity of systems to continue over long periods) and addresses higher socioeconomic and ecological outcomes (Pretty, 2007).

Once sustainability objectives are exactly prioritized, indicators are useful tools for measuring progress toward the desired state as a result of changes to management. To monitor the development of sustainability, a holistic assessment is important, since evaluations focusing on specific aspects may lead to incorrect conclusions about the real conditions on the ground (Häni et al., 2007). Because sustainability is a multipurpose concept, it is also important to use different environmental, social, agronomic and economic indicators when evaluating the sustainability of whole agro-ecosystem performance. Any developed method for assessing agricultural sustainability should consider all possible farming activities and also their side effects (Allahyari et al., 2016). Mahdavi Damghani et al. (2006) investigated the agricultural sustainability in wheat-cotton rotation using different indicators. The most important indicators in their study were: crop yield, agrochemical application, irrigation methods, machinery application, biodiversity of agricultural crops, and socio-economic factors. They concluded that crop yield and irrigation are the most important factors which could affect agro-ecosystem sustainability. Lavasani et al. (2015) studied the ecological sustainability of greenhouse production systems using different indicators and showed that crop species diversity, crop residual management and accessibility to inputs were the most important factors affecting the sustainability of production system.

Most of the works on sustainability indicators for agro-ecosystems have focused on three goals, that is to satisfy human food and fiber needs, to enhance environmental quality and the resource base, and to sustain the economic viability of agriculture, whereas social indicators for the fourth goal (to enhance the quality of life for farmers and society as a whole) are less developed and understudied (Jackson-Smith, 2010).

The current study was performed to determine the trend of changes in different indexes of sustainability in agricultural systems of Golestan province during a 10-year period.

MATERIALS AND METHODS

The current survey was conducted in order to study the sustainability of agricultural systems in Golestan Province in northern Iran during the period of 2002-2011. The required data were obtained from official statistical database (Ministry of Agriculture Jihad, 2015). Different indexes were selected and calculated based on their scientific definitions (Binderand Feola, 2013; Koocheki et al., 2008; Wezel et al., 2014; Xu & Mage, 2001). Also, the total numerical value of sustainability was calculated using 21 different indexes for individual years (Table 1).

Cropping intensity measures the area of land use for cropping purposes during a given year (Sajjad et al., 2014). Cropping intensity index for irrigated and dry land crops is calculated by

Equation (1): Cropping intensity = (area under cultivation of crops/ total arable land)

In order to quantify agronomic diversity using Equation (2), the Shannon–Wiener diversity index was calculated (Bell & Morse., 2008).

$$H= -\sum (P_i) \times (log^2 P_i) \quad (2)$$

$$\text{Pi} = ni / N$$

where n_i is the area devoted to plant species i and N is total area under cultivation of crops.

Because of the higher water use efficiency in pressurized irrigation system, the ratio between the area of fields irrigated by pressurized systems and total irrigated fields were used to indirectly calculate water use efficiency index. The production costs were estimated using production costs of one-ton wheat in different years.

Because of diverse nature of the selected indexes and their wide ranges, in order to facilitate their comparison, they were all normalized using Equation (3), in that *Xnorm* is the normalized value of each index, and *Xmax* and *Xmin* are the highest and lowest values of X, respectively. Equation (3) was used for the positive indicator which can improve the sustainability of agro-ecosystems whereas Equation (4) was employed for the negative indicator. The highest values of *Xnorm* or *Xnorm2* represented the most positive effects of index on total calculated value for sustainability.

$$Xnorm = \frac{(X - X\min)}{(X\max - X\min)} \quad (3)$$

$$Xnorm\,2 = 1 - Xnorm \quad (4)$$

Because the selected indicators did not have similar importance, in order to improve the calculations, weights were assigned to them using the questionnaires filled by experts and agroecologists.

After the above mentioned equations were applied to calculate the indicators in different years, the lowest value of Xnorm was set to zero and highest value was set to maximum weight of each indicator. For example, the lowest value of annual precipitation was obtained in 2008; therefore, it was set to zero in that year. In contrast, the highest value of annual precipitation was recorded in 2004 and therefore the highest value of Xnorm (+3) was calculated for 2004.

RESULTS AND DISCUSSION

The calculated and normalized values for different studied indicators are presented in Table 1. The highest value of agricultural sustainability was calculated for 2009 whereas the lowest was observed in 2002. Therefore, the current paper mainly focused on these two years and on the reasons for higher sustainability in 2009. Since 2009, the calculated value of sustainability has decreased slightly but it has been still higher than that of first years of study (Figure 1). Higher agricultural sustainability in 2009 is related to improvement in different indexes. In 2009 compared to 2002, the calculated values of five indexes (i.e. agronomic diversity, cropping intensity, production cost, field size and average annual precipitation) were decreased, but the remaining 16 indexes exhibited enhancements. Among the increased indexes (in 2009), the highest positive effect was related to lower application of chemical pesticides, higher yield of rainfed crops, and higher water use efficiency. Because numerous indexes were calculated in this paper, mainly discuss the first three indexes which had higher positive or negative effects on total value of sustainability (Figure 2).

More than 25% of change in sustainability value in 2009 was accounted for by chemical pesticides (Figure 2). The higher rate of pesticide

Table 1
Calculated and Normalized Indicator of Agricultural Sustainability in Different Years

No	Indicator	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Weight
1	Agricultural land per capita	1.14	1.20	1.53	1.85	1.89	2	0	1.17	1.11	0.28	+2
2	Field size	0.88	0.85	0.58	0.31	0.17	0	1	0.22	0.11	0.12	-1
3	Cropping intensity	1.16	1.68	1.10	0.57	0.31	0	2	0.39	0.20	0.21	-2
4	Dry land cropping intensity	0.42	0.44	0.69	0.92	0.76	1	0.47	0.56	0.32	0	+1
5	Dry land area/irrigated land area	0.91	0.83	1.34	1.85	1.48	2	0.91	1.06	0.56	0	+1
6	Agronomic diversity	2.1	3	1	0	1	0.5	3	0.6	1	0.9	+3
7	Area under cultivation of nitrogen fixing	0.38	0	0.06	0.11	0.43	0.35	3	0.77	1.25	1.14	+3
8	crops	2.26	2.57	3	2.82	1.13	1.53	0	2.02	1.02	2.74	+3
9	Mean of annual precipitation	0.04	0.04	0	0.41	0.38	0.67	2	1.70	1.99	1.94	+2
10	Machinery applications	0	0.11	0.37	0.74	1.31	1.49	1.73	2.02	2.37	3	+3
11	Water use efficiency	0.48	0.44	0.37	0.23	0	0.29	0.27	0.50	0.55	1	-1
12	Application of chemical fertilizers	0.06	0.07	0	0.23	0.91	2.11	3	2.62	2.36	2.76	-3
13	Application of chemical pesticides	0.39	0.43	0.32	0.16	0	0.44	0.26	0.72	0.83	2	+2
14	Nitrogen use efficiency	2.41	3	2.33	2.16	0.99	2.53	0.40	2.46	1.29	0	+3
15	Yield of irrigated cereal	0	0	2.36	2.36	2.34	3	1.51	2.47	2.66	1.33	+3
16	Yield of dryland crops	0.25	0.43	0.59	1	0.58	0	1.11	1.31	3	0.80	+3
17	Yield of pulses	2.19	2.40	2.72	2.96	2.38	3	2.95	2.61	1.25	0	+3
18	Yield of industrial plants	0	0.21	0.23	0.49	0.59	3	1.53	1.03	1.47	2.15	+3
19	Yield of vegetable crops	1.93	1.99	2.30	3	1.99	1.73	0	3	1.35	1.89	+3
20	Yield of kitchen garden plants	1	0.97	0.92	0.71	0.42	0.49	0	0.28	0.27	0.26	-1
21	Production costs	0.22	0.23	0.50	0.76	0.89	1	0	0.84	0.95	0.94	+1
	Arable land/total area ratio	18.22	20.89	22.31	23.64	19.95	27.13	25.14	28.35	25.91	23.46	
	Sustainability value (sum of 21 indicators)											

† (+) and (–) presenting the positive and negative effects of studied indicator on agricultural sustainability

application in 2002 had a significant role in decreasing the sustainability value in this year versus the remaining years. In general, application rate of pesticides has decreased significantly since 2007 and therefore the normalized value for application of chemical pesticides has increased in these years. Less use of chemical inputs in the second half of the studied period was mainly attributed to the increased price of these products.

For most crops, the loss of yields due to pests could reach 20- 30% and therefore pesticides

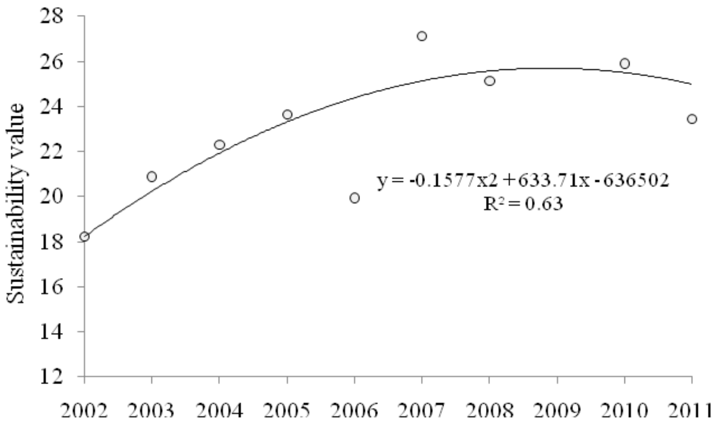

Figure 1. The trend of the variations of sustainability value over the different years

play an important role in protecting agricultural crops against pests. However, the indirect costs of pesticide use to the environment and public health have to be balanced against these benefits (Altieri & Nicholls, 2005). The main environmental impact of pesticides is the direct and/or indirect damages which they cause to plants, animals, and microorganisms. These negative effects are not usually restricted to the fields because during the applications, pesticides drift away in the air and infiltrate into the soil (Gil & Sinfort 2005). During soil erosion, some soluble pesticides may be washed out in runoff water and leach into rivers and lakes (Chopra et al., 2011). The increase in chemical pesticide application has resulted in loss of biodiversity, which has important ecosystem functions and services, especially in biological control and pollination (Schneiker et al., 2016). Pesticides could also affect food webs and competition ability of different species (Köhler & Triebskorn 2013).

Application of agrochemicals could directly affect the sustainability of agriculture due to farmers' health threats. Farmers and other people living in rural areas in which pesticides are intensively used may be indirectly exposed to these chemicals, through off-target pesticide drift from agricultural applications in particular (Lee et al., 2011). Irrational application of chemical inputs is against the goals of sustainable agriculture; therefore, different countries looking for solution to curb the use of these inputs, like taxation on pesticides and fertilizers or removal of subsidies for these agrochemicals, would discourage excessive use. Different methods such as integrated pests management, biological control of pests, crop rotation and the use of spatial or temporal crop diversity can be resorted to in order to reduce the need for the production of new pesticides (Tilman et al., 2002).

The second important index which had a significant role in higher value of sustainability in 2009 was the yield of dry land crops. This index contributed about 24% to the increased amount of sustainability value (Figure 2). Whereas under rainfed conditions, rural households are susceptible to considerable income risks, and diversification opportunities are limited in providing a natural hedge against the income variability (Gaurav, 2015), the low external input and energy use in the rainfed agro-ecosystems of Golestan Province lead us to the conclusion, that rainfed systems are more sustainable albeit their likely instability (Kerr et al., 1996). The yield of rainfed crops is usually lower than that of irrigated crops. The improvement of the yield of rainfed crops without any changes in the application of external inputs would enhance the resources use efficiency. Although water productivity is very low in rainfed agricultural systems (Garcia-Tejero et al., 2011), the salinization is not a problem in these systems due to the natural flushing of salts. Evidence has been documented suggesting that the lower water productivity in rainfed agricultural systems is related to management aspects rather than to low physical potential (Kijne et al., 2003). While main strategies for water management in industrial agriculture have focused on irrigation (use of blue water), a global analysis of green and blue water availability showed that water shortage is primarily an issue of blue water and significant opportunities are still possible in the management of rainfed areas, that is the green water resources (Rockstom et al., 2009).

More than 19% of the variation of sustainability value of agro-ecosystems in 2009 was related to water use efficiency (Figure 2). Given what was said the direct and indirect role of water in agricultural sustainability of the studied region is apparently very important.

Water is considered the most important resource for sustainable development in many countries, especially in arid and semiarid countries such as Iran. Improved irrigation methods and technologies play an important role in boosting water use efficiency and water productivity (Popescu & Jean-Vasile, 2015). Water can be considered the most critical resource for sustainable agriculture development worldwide, and the sustainable use of irrigation water is a priority for agriculture in arid and semi-arid regions (Chartzoulakis & Bertaki, 2015). Other researchers have also reported the role of sustainable irrigation management in sustainable agriculture. Sustainable irrigation means applying the correct amount of water at the appropriate time for optimal conditions of crop growth, minimizing overwatering, leaching, and runoff (Garcia-Tejero et al., 2011).

In order to increase water use efficiency, it is essential to find appropriate crops using minimal water, to use application methods that minimize the loss of water by evaporation from the soil or infiltration of water beyond the depth of root zone, and to minimize the losses of water from delivery systems and storages (Chartzoulakis & Bertaki, 2015).

Among the other indexes which had positive effects on sustainability value in 2009, the role of yield improvement, increased acreage of nitrogen fixing plants and nitrogen use efficiency enhancement is well documented in agricultural sustainability (Figure 2).

In general, the yields of the all studied crops were increased in 2009 (Figure 2). The higher yield of different crops in this year could be related to the improvement of management methods which has resulted in higher resources use efficiency. Low crop yield was stemmed from inadequate soil fertility, which rendered plants unable to use the available water under nutrient stress conditions, resulting in low water use efficiency and difficulties for sustainable agriculture (Ozier-Lafontaine & Lesueur-Jannoyer, 2014). When the yield of a crop is increased more rapidly than the use of external inputs, it appears that input use efficiency will improve and, therefore, it will be possible to mitigate the negative pressure on the natural environment (Pintér & Herren, 2007).

Since atmospheric nitrogen is a renewable and stable resource in the atmosphere, symbiotic fixation of nitrogen in agricultural ecosystems is a sustainable practice. In contrast to the large

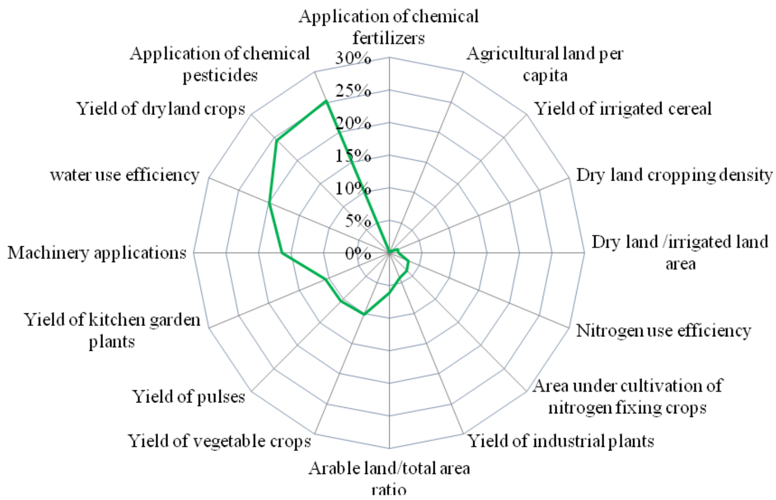

Figure 2. The share of different positive indexes in the variation of sustainability in 2009 compared with 2002

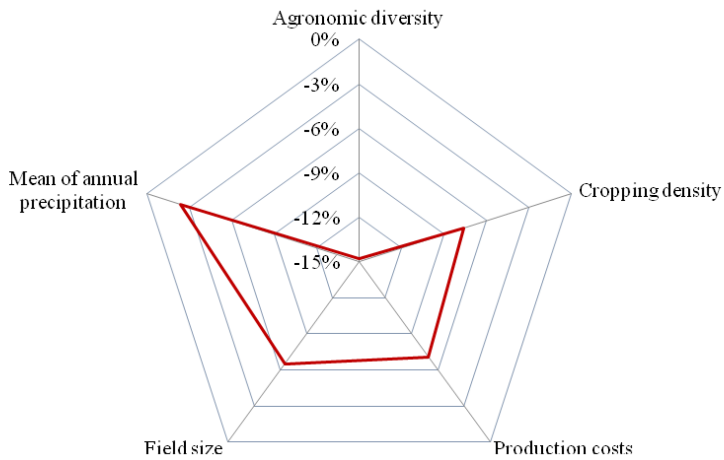

Figure 3. The share of different negative indexes in the variations of sustainability in 2009 compared with 2002

amounts of fossil energy required for the production of chemical nitrogen fertilizers, the required energy for biological fixation of nitrogen is free of charge and is derived from photosynthesis. Considering the environmental conditions, precision application of nitrogen fertilizer at right form, source, rate, time and place targets both sustainable yields and high nitrogen use efficiency and will finally benefit farmers, society, and the environment (Lichtfouse, 2012).

Among the indexes decreased in 2009, the agronomic diversity was the most important factor which had high negative effect (-14.8%) on final value of sustainability (Figure 3). Increasing crop diversity using different methods such as agronomic rotations, intercropping, and using different genetic varieties can contribute to improving soil quality and managing pests and diseases, and finally increasing the sustainability via saving production costs. In conventional agricultural methods, the production of a few species of crops, with limited rotations or crop diversity, runs counter to the natural tendency for more diversity that can result in high-quality soils (Jackson-Smith, 2010). A farmer who produces different crops can be more sustainable than a farmer who is specialized in one crop, because diversity provides more economic stability, and stability in turn provides sustainability (Jordan, 2013). In sustainable agroecological practices, the question of diversification is inevitable, as these practices are based on ecological processes and provision of ecosystem services. Crop rotation is a more classic way to increase crop diversity in an agricultural ecosystem. It consists of managing the crop succession to improve the positive interactions among crops (Wezel et al., 2014).

In 2009, about -7.6% of sustainability value variations was accounted for by cropping intensity (Figure 3). The lower the cropping intensity index was, the higher the share of cultivated land in total arable land was. Putting more land under cultivation meaning that farmers have to use more resources and leave less fallow land. Appropriate duration of fallow helps restore the fertility of land whose nutrients are depleted and decrease the fertilization requirements in the subsequent growing seasons. A study in North America and Europe has showed that land withdrawn from conventional production of crops obviously enhances biodiversity (Van Buskirk & Willi, 2005).

Decreasing cropping intensity can result in wildlife-friendly farming which is a practice of setting aside land that will not be fully developed or cultivated by farmers. This land will be set aside so that biodiversity will have a chance to establish itself in areas with agricultural fields. At the same time, the producer is attempting to lessen the amount of fertilizers and pesticides applied on the fields so that organisms and microbial activity will have a chance to establish themselves in the soil and habitat (Green et al., 2005). The reduction of the cultivated area may have another indirect advantage such as the promotion of soil biological activity and soil biodiversity. Many studies have suggested a positive relationship between soil biodiversity and ecosystem services. For example, more earthworms were found in uncultivated lands with no tillage (Capowiez et al., 2009) which, in turn, increased porosity of soil and thus improved infiltration for water and plants roots.

Another index which negatively impacted agricultural sustainability in 2009 was production costs. In this year, -7.1% of variations of sustainability value was captured by production costs (Figure 3). Higher production costs of agricultural crops in these years were mainly related to higher labor costs, inflation and devaluation of currency which led to higher costs for imported inputs. Given the economic dimension, the goal of sustainable agriculture is to provide more profitable farm income by decreasing the production cost and enhancing the quality of life for rural families and communities.

Increasing production costs can pose a threat to economic dimension of sustainable agriculture. Strategies to improve economic security at the farm level include reducing production costs, increasing the value of farm products, and diversifying income streams. Production costs and prices can be dynamic spatially and temporally and depend on different factors including policies, market, and geographic location (Jackson-Smith, 2010). A sustainable farm should be able to be viable in economic terms, livable for the farmer and his family, and ensure the health of the environment (Zahm et al., 2007). Increasing rural income and economical productivity significantly contribute to enhancement of sustainability in the agricultural system (Bosshaq et al., 2013). In some cases, it has been noticed that agricultural sustainability is independent of economical sustainability, and vice versa. Therefore it is possible to have good economic sustainability while preserving the quality of the environment. Results of previous study showed that there is no relationship between economic viability (which is an indicator of farmer income) and agro-economic sustainability (Zahm et al., 2007).

CONCLUSION

According to the results, the second half of the studied period has experienced the improvement of most sustainability indexes but the most important cause of sustainability value enhancement was lower application rate of chemical pesticides. In fact, this was related to farmers' environmental concerns to a lesser extent but to higher prices of these inputs during 2007-2011 to a greater extent. Therefore, it seems that economic dimension of sustainability should be paid more attention. The study suggests that the indirect cost of production systems such as soil erosion, water pollution, deforestation, loss of wildlife diversity and habitats and human health can be also considered for the assessment of agricultural sustainability.

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