Asian Journal of Plant Sciences

ISSN 1682-3974

science alert

ANSInet
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Asian Journal of Plant Sciences 5 (3): 559-562, 2006
ISSN 1682-3974

Studying the Sustainability of a Wheat-cotton Agroecosystem in Iran

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Abstract: In order to develop a Sustainability Index (SI) for quantifying the sustainability of a wheat-cotton agroecosystem, a study was conducted in 2003 in the Khorassan province. Data of socio-economic, agronomic and ecological indicators were collected using 518 questionnaires. Results showed that only 18.6% of farmers gained the half or more of SI score and the mean SI score was 44.0 which indicate that these agroecosystems are not sustainable. Results of this study are in consistent with other reports in other regions of the country. Livestock production, crop production and water and irrigation indicators had the lowest score (6, 31 and 37, respectively). The backward stepwise regression analysis indicated that SI can be predicted from a linear combination of field size, wheat yield, crop residue management, crop income and education and extension services, while application of chemical fertilizers did not add to the prediction ability of SI. Results also showed that any progress in farmers' education, economic viability, crop production management and water use efficiency could improve overall sustainability of these agroecosystems substantially.

Key words: Sustainability index, wheat-cotton agroecosystems, Khorassan

INTRODUCTION

Advances in agriculture during last century which came from intensive works of scientists, policy makers and farmers have resulted in increase of mean world wheat yield from 0.9 t ha^{-1} at the beginning of last century to 2.6 t ha^{-1} at the end of twentieth century (Slafer, 1994), 103% increase in barley yield in India during 1950-1980 (Evans, 1993) and increase of rice harvest index from 0.30 to 0.50 (Sinclair, 1998). These progresses however had negative ecological, environmental and socio-economic consequences including soil degradation and erosion, surface and underground water pollution to agrochemicals, deforestation and decline in social structures in rural societies and weakening of traditional cultures and agroecosystems. So, reconsideration and revision of conventional systems in agriculture and food production is necessary. We should change the current management approaches and design new ecologically-oriented agroecosystems which are sustainable, while produce enough food and fiber.

Sustainability Index (SI) is a quantitative value that measures the sustainability of an agroecosystem. Each SI consists of several sustainability indicators which are biological, physical, chemical and socio-economic variables affecting the structure and function of the ecosystem. Sustainability indices reflect the viability of an agroecosystem quantitatively and are useful tools for evaluating the quality and efficiency of the system as well as making suitable decisions in its management (Koocheki, 2003). There are some works trying to quantify the sustainability of agroecosystems in Iran. Hayati and Karami (1996) developed an index to study the sustainability of wheat fields in Fars province. In this study, the sustainability is calculated as a function of parameters like wheat yield, crop rotation, growing legumes, applying organic fertilizers, green manure and crop residue for wheat nutrition, conservation tillage as well as application of agrochemicals including N and P fertilizers and pesticides. Results showed that more than half of fields were not sustainable. Koocheki (1998) quantified the sustainability of agroecosystems in three province of Iran using 31 agronomic, ecological and socio-economic indicators and reported that theses systems are relatively sustainable.

The objectives of this study were quantifying agroecological sustainability of wheat-cotton agroecosystem in Iran, determination of critical points of the system and evaluating management approaches for improving its sustainability.

MATERIALS AND METHODS

Eighty two indicators selected to develop a sustainability index. The indicators classified in 9 groups

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Table 1: Indicator groups and their score from total 100 of SI

Indicator groups	Max. score
Socio-economic	29.5
Fertilizers and pesticides	14.5
Crop residue management	5.75
Water and irrigation	14.5
Tillage and machinery	15.75
Crop production	7.5
Livestock production	3.0
Agrobiodiversity	6.0
Weed management	3.5
Sustainability index	100.0

as socio-economic, crop production, livestock production, chemical fertilizers and pesticides, crop residue management, water and irrigation, tillage and machinery, agrobiodiversity and weed management indicators. The weighting sum method (Andreoli and Tellarini, 2000) used to calculate the sustainability index. Each indicator had a score ranging from zero to a maximum value. The highest and lowest score were for the most favorable and the worst conditions, respectively. The final value of 100 for the SI was the sum of all indicators' score. The indicators used in the study and their score from total 100 are shown in Table 1. After calculating SI, the backward stepwise regression was done to select the most significant indicators in determining SI. In this method, SI selected as dependent and the indicators as independent variables and then analyzed and the indicators that had not significant effect in SI estimation were eliminated. After that, the model equation of determining SI and crop yield were extracted using multiple linear regressions.

The data of indicators gathered from three counties in Khorassan province (Neyshabour, Bardaskan and Ferdows) using 518 questionnaires. The questionnaires passed the validity test and were filled during interview with farmers in the wheat-cotton agroecosystems.

RESULTS AND DISCUSSION

The average score of SI in the province was 44.0 (from 100) which means this agroecosystem is not ecologically sustainable (Table 2). Only 0.8% of farms got at least 60% of the SI score (Table 3). Koocheki (1998) reported that SI score of Isfahan, Mazandaran and Azarbayejan Gharbi provinces were 61, 60 and 51, respectively. Hayati and Karami (1996) showed that 51.3% of farms in Fars province classified as unsustainable and only 8.9% of them were qualified as sustainable.

The lowest scores observed in livestock production and crop production groups (Fig. 1). Only 24% of farms had the yield of 4 ton ha^{-1} or more in wheat production

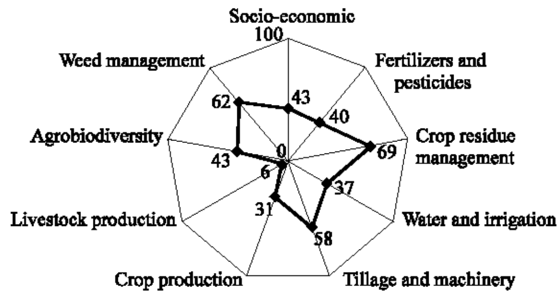

Fig. 1: Observed score (%) of different indicator groups in wheat-cotton agroecosystem

(Table 4). Kelantari and Mirgowhar (2002) reported that only 38% of wheat growers in Isfahan and Tehran province reached the yields equal or more than 4 ton ha^{-1}. In another study, it was shown that 8 percent of farms harvested this record (Hayati and Karami, 1996). The more or less same results were observed in cotton yield (Table 4). The low yields can be attributed to factors such as low water use efficiency (dry matter production per unit irrigation water, Table 5) and low educational level of farmers, as 82% of farmers were illiterate or low-educated and only 5% of them had academic education. The most significant indicators in determining wheat yield were calculated using backward stepwise analysis. The model coefficients which determined by multiple linear regression are:

$$Y = 641.5+(0.169*A)+(1.77*B)+(0.00683C)+(210.2D)+(144.1E)-(264F)+(186G)+(306.1H)+(35.8I)+(318.1J)+(0.000207K)+(0.00000507L)-(0.00000574M)+(0.900N)+(105.1O)+(227.2P)-(72.9Q)$$

Which 641.5 is the model constant, Y is sustainability index and A to Q are, respectively wheat yield, N application, K application, manure, pesticide application, the number of applied fungicides, burning the crop residue, feeding the wheat residue for livestock, incorporation of residue to soil, selling crop residue, water use efficiency, income from each hectare of wheat, income from livestock, non-agricultural income, total planting acreage, input availability, financial support availability and access to education and extension services. As it can be seen, the wheat yield dependency to N fertilizer is weaker than its dependency to water use efficiency; i.e. by applying 100 kg ha^{-1} N fertilizer, the yield would increase only 17 kg ha^{-1}, while 0.1 unit increase in water use efficiency would improve the yield by 318 kg ha^{-1}.

Socio-economic analysis of the system showed that these indicators had also low scores. The results of

Table 2: SI score of wheat-cotton agroecosystem in three counties

	Observed score			% Score from maximum		
Indicators	Neyshabour	Bardaskan	Ferdows	Neyshabour	Bardaskan	Ferdows
Socio-economic	12.50	13.63	12.85	42	46	44
Fertilizers and pesticides	6.01	5.88	4.91	41	41	34
Crop residue management	3.95	2.86	4.67	69	50	81
Water and irrigation	5.44	4.88	5.46	38	34	39
Tillage and machinery	9.27	9.36	8.29	89	59	53
Crop production	2.14	3.14	2.37	29	42	32
Livestock production	0.26	0.06	0.04	9	2	1
Agrobiodiversity	2.51	2.12	3.07	42	35	51
Weed management	2.36	1.56	1.94	67	45	55
Sustainability index	44.40	42.40	43.60			

Table 3: Frequency of farms based on SI scores

SI score range (from 100)	Frequency No.	%
20-29.9	3	0.6
30-39.9	143	27.6
40-49.9	275	53.1
50-59.9	93	18.0
60-69.9	4	0.8

farm size indicate that 30% of the farms are smaller than one hectare (Table 6) which is consistent with other reports in the country (Hayati and Karami, 1996). It is evident that small size of fields limits the possibility of applying machinery and therefore reduces the efficiency and productivity of the agroecosystem. Zaibet and Dharmapala (1999) have demonstrated the direct relationship of field size and crop yield in Oman. Furthermore, evaluating farmers access to financial supports like loan and insurance showed that these facilities are available only for about one third of them (Table 7). It means that any reduction in the farmers' agricultural income due to climatic or any other factor will substantially threaten their life stability. This is the reason why Farshad and Zinck (2001) stated that economic viability is one of the primary pillars of sustainability. Webster (1997) noted that improvement of economic welfare of rural societies is the most important factor in accepting sustainable agriculture by farmers. In addition, financial supports have an important role in stabilizing rural livelihood in the cases which farmers deal with unfavorable climatic and agronomic condition (Uri, 2001). Koocheki (1998) listed the economic pressure as a main cause of environmental deterioration in three province of Iran.

The relation of wheat yield and SI indicated that other variables than crop yield affect the sustainability of the system, because in a given yield, there is a wide range of SI score (Fig. 2). In other words, the crop yield is not the main and sole determinant of SI. The modeling of SI based on the studied indicators resulted to the following equation:

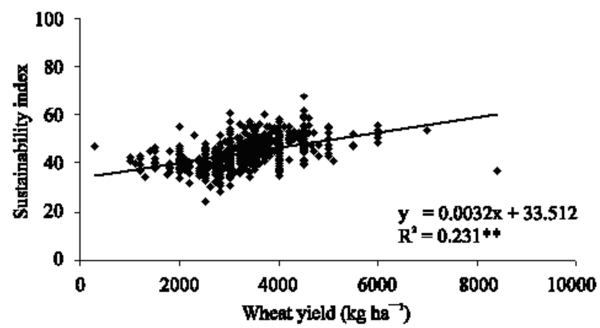

Fig. 2: Linear regression of wheat yield against sustainability index scores in the wheat-cotton agroecosystem in Khorassan province

$$SI = 42.1-(0.537A)+(0.001B)-(0.683C)+(3.24D) -(4.74E)-(0.018F)-(4.86G)+(5.45H) -(0.000006I)+(1.52J)+(7.58K)$$

Which 42.1 is the model constant and A to K are, respectively wheat acreage, wheat yield, crop diversity, pesticide application in both crops, number of applied fungicides in cotton, incorporation of wheat residue to soil, selling wheat residue, incorporation of cotton residue to soil, income from cotton, distance of farm and farmer home and access to education and extension services. It is obvious in this model that parameters like application rate of N, P and K fertilizers had not significant effect on determining SI, while indicators such as crop diversity or crop residue management were the main variables to predict SI in this agroecosystem.

Results of this study cleared some critical points of wheat-cotton agroecosystem in the province. Farmers' education and literacy level was a main cause of low values of SI. We should not except to observe efficient agroecosystems with the farmers who are mostly illiterate or low-educated. Therefore, it is necessary to develop educational programs for farmers to increase their educational level and also the efficiency of agricultural

Table 4: Frequency of reported wheat and cotton yields in the wheat-cotton agroecosystem in Khorassan province

	Crop yield ($kg\ ha^{-1}$)							
	Wheat				Cotton			
	Less than 2000	2000-2999	3000-3999	4000-8000	Less than 2000	2000-2999	3000-3999	4000-6000
Frequency (%)	5	26	45	24	21	45	28	6

Table 5: Frequency of water use efficiency ranges in the wheat-cotton agroecosystem in Khorassan province

	Water use efficiency ($kg\ m^{-3}$)			
	0.20-0.49	0.50-0.75	0.76-1.00	1.00-1.20
Frequency (%)	18	74	7	1

Table 6: Field size range in the wheat-cotton agroecosystem in Khorassan province

	Field size (ha)			
	Less than 1	1.0-2.0	2.1-5	More than 5
Frequency (%)	30	49	15	6

Table 7: Frequency of farmers access to production input, financial and extension services in the wheat-cotton agroecosystem in Khorassan province

	Input and service availability for farmers		
	Crop production inputs	Financial services	Extension services
Frequency (%)	71	34	68

practices in the field. Another important factor which should be considered is improving farmers' livelihood through empowerment of economic viability of rural societies. In addition, as any increase in crop and livestock production will result in income increasing of farmers, any practice and management approach that improve the yield while maintain environmental health and sustainability would be appreciated.

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