J. Agr. Sci. Tech. (2015) Vol. 17: 1409-1420

Assessment of Agricultural Farming Systems Sustainability in Hamedan Province Using Ecological Footprint Analysis (Case Study: Irrigated Wheat)

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ABSTRACT

Ecological footprint analysis in agriculture is a new and evolving subject. The main purpose of the study was to assess environmental sustainability of conventional and conservation tillage systems using ecological footprint analysis in Hamedan Province. Global hectares (gha) were used to measure the ecological footprint unit. Data was collected through questionnaires and use of cross-sectional multi-stage cluster sampling in 2013-2014 cropping year. Results revealed a significant difference in global hectares (gha) between ecological footprints in conventional (2.96) and conservation (2.84) systems. Both cropping systems used agricultural lands more than the ecologically productive land required to offset the environmental impact of different farming activities, and are therefore considered unsustainable. However, conservation systems proved to be more environmentally sustainable. The ecological footprint of fuel factor (gas oil and electricity) in both cropping systems had the highest impact on environmental sustainability: 49.70% and 47.22 percent of global hectares; respectively. Although environmental pollution was reduced slightly by the conservation system, estimated footprint based on gha was worrying. Addressing these challenges requires a national commitment which would not be possible without government intervention.

Keywords: Carbon footprint, Global hectare, Tillage systems, Sustainable agriculture.

INTRODUCTION

With the advent of the industrial age, external inputs have been particularly emphasized in agricultural activities; chemicals such as fertilizers and pesticides and machineries have increased agricultural activity and, therefore, have caused an overexploitation of land and natural resources (Passeri *et al.*, 2013). In previous decades, environmental issues in various fields such as agriculture and industry attracted greater attention due to the followings: the book entitled Silent Spring, which dealt with the use of fertilizers and chemical pesticides (Carson, 2002), the economic theory of non-renewable resources put forward by Meadows (1972), and the concept of sustainability in the report entitled ‘Our Common Future’ (Gerbens-Leenes *et al.*, 2003). Given the diversity of environmental impact of agriculture such as destruction of natural resources (water and soil), pollution, loss of biodiversity of agricultural ecosystems, increased natural hazards (e.g. global warming) with its associated impacts (e.g. droughts, climate change, floods), and their aggregate effects on food quality and consumer health (Punkari *et al.*, 2007). However, in Iran, there have been so far no serious endeavors and research to

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undertake the environmental impact assessment of the various practices affecting the resources (Aghnoum *et al.*, 2014). Several methods for assessing these impacts have been proposed (Wiedmann and Minx, 2008; Panko and Hitchcock, 2011; Agostinho and Pereira, 2013). These methods were developed taking into consideration objectives, concepts, levels of impact and potential application. One of the most important quantitative methods in this respect was the Ecological Footprint Analysis (EFA).

The concept of footprint, which was derived from ecological footprint, was first introduced into the scientific community by Rees and Wackernagel (1996). Subsequently, a variety of footprint indicators were proposed to complete the ecological footprint. The most important ones are energy footprint (Rees and Wackernagel, 1996), water footprint (Hoekstra and Hung, 2002), “emergy” footprint (Zhao *et al.*, 2005), “exergy” footprint (Chen and Chen, 2007), carbon footprint (Wiedmann and Minx, 2008), ecological footprint of different species of life (Yaap *et al.*, 2010), chemical footprints (Panko and Hitchcock, 2011), phosphorus footprint (Wang *et al.*, 2011), and nitrogen footprint (Leach *et al.*, 2012). The ecological footprint has been proposed as a powerful communication tool to inform people about the environmental impact caused by excessive production and consumption. The ecological footprint is defined as the area of productive land and water required by the ecosystem to produce resources and assimilate the wastes (Cerutti *et al*., 2013). In this study, ecological footprint is defined as the area of productive land required to compensate the environmental impact of different farming activities.

Ecological footprint methodology is based on integrating detailed available data. There are two main methods for calculating the ecological footprint: Life Cycle Assessment (LCA) and Input-Output Analysis (IOA) (Agostinho and Pereira, 2013). These two methods have been criticized recently because of the fact that assessment of the ecological footprint requires a different approach at macro- compared to micro-levels like a city, province and, for particular agricultural activities, on a farm. Therefore, in the first decade of the 21st century, Place–Oriented Approach (POA) as a new method of ecological footprint was proposed by scientists like, Kissinger and Gottlieb (2012) and Guzman *et al.* (2013). This method combines the two previous techniques and focuses more specifically on a particular place. In addition to being flexible, it is able to calculate the footprints using data from different locations; which is an aspect considered in this study.

Using the ecological footprint analysis in agriculture is a new and evolving subject. Ecological footprint indicator is an appropriate index for agricultural production and a good criterion for evaluating energy consumption, greenhouse gas emissions, nitrates’ contamination from fertilizers and pesticides, land and water use in agriculture (Anielski and Wilson, 2010). Ecological footprint can assess the sustainability of agricultural systems (Cerutti *et al*., 2013). From an environmental point of view, sustainable agricultural activity occurs when long-term use of resources is induced by the environmental carrying capacity. Therefore, ecological footprint evaluation of agriculture is the first step in the overall assessment of agricultural sustainability (Payraudeau *et al*., 2005). Several studies have used the ecological footprint as an indicator for assessing sustainability of agriculture in order to determine the environmental impact of agricultural activities (Passeri *et al.*, 2013; Crishna, 2007; Cheng *et al*, 2011; Xu *et al.*, 2013). The main components of this approach, particularly in agricultural activities, are consumption of fuels, inputs, labor, agrochemicals, pesticides, machinery as well as productions and waste products. In general, research in this area can be classified into several categories: studies dealing with the impact of management practices on environmental effects of agricultural activities by using ecological footprint analysis (Passeri *et al*, 2013; Azad and Ancev, 2010; Phong *et al*, 2010; Crishna, 2007); works calculating ecological footprint based on energy consumption and products (Tittonell and Giller, 2013; Dong *et al.*, 2013; Anielski and

[DOR: 20.1001.1.16807073.2015.17.6.21.2]

Wilson, 2010; Cheng *et al.*, 2011); inquiries studying the agricultural ecological footprint and its suitability based on the Life Cycle Assessment (Gan *et al.*, 2011; Schafer and Blanke, 2012; Knudsen *et al.*, 2013); studies considering biodiversity in agricultural activities and then evaluation of the footprint (Galli *et al*, 2014; Ridoutt and Pfister, 2013; Gan *et al.,* 2012); and finally, those calculating the ecological footprint based on cropping succession (Xu *et al.*, 2013; Wood and Dey, 2009). Each of these studies evaluates the sustainability of agriculture using ecological footprint analysis in different ways.

There are studies that have specifically examined the ecological footprint of wheat production (Gan *et al.,* 2012; Gan *et al.*, 2011). In these studies, the Energy Efficiency Index (EEI) was used to determine the sustainability. In all of these studies, global hectare was used to demonstrate the ecological footprint unit. The global hectare is a term derived from a method presented by Rees and Wackernagel (1996). A global hectare (gha) is a common standard for footprint comparisons between various land use types in the world (Anielski and Wilson, 2010).

In this research, the ecological footprint was used as a criterion to calculate the ecological footprint in wheat production. This method has been developed and evaluated for comparing the sustainability of conventional and conservation tillage systems based on energy consumption by using place-oriented method proposed by Kissinger and Gottlieb (2012) and Guzman *et al.* (2013).

MATERIALS AND METHODS

The Area of Study

Hamedan Province is located in the west of Iran and has a cold semi-arid climate with an annual rainfall of 340 mm. The study area lies between latitude 33° 59´ and 35° 48´ N and longitudes 47° 34´ and 49° 36´ E Greenwich meridian (Figure 1).

In Iran, wheat is the most important crop and is cultivated in almost 50 percent of total arable land every year (Zeinali, 2009). Annual total products of agricultural sector

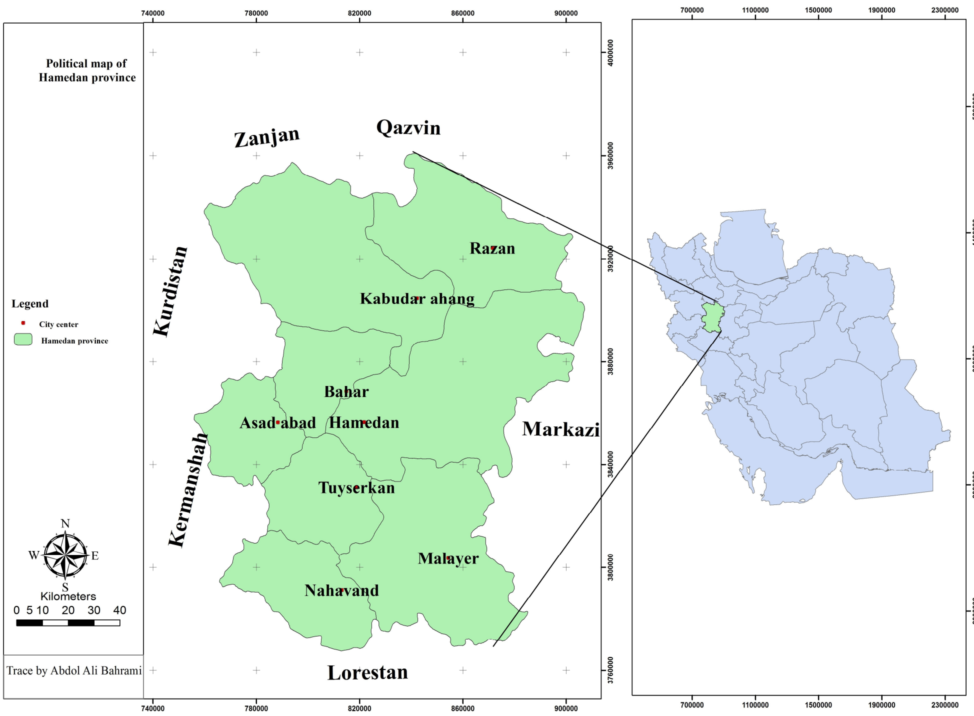

Figure 1. Map of study area.

[DOR: 20.1001.1.16807073.2015.17.6.21.2]

in Hamedan was more than 5 million tons, constituting 5 percent of agricultural production of Iran (Hamedan Jihad of Agriculture Organization, 2014). Hence, agriculture is the main economic activity and principal land use with main crops being wheat and barley in the study area (Hamedan Provincial Government, 2011). Hamedan's annual cropping plan of wheat in the crop year 2013-2014 is illustrated in Table 1.

Research Methodology

In this cross sectional and descriptive research, the target population consisted of farmers who were members of agricultural production cooperatives (N= 6,673) in Hamedan Province. These farmers followed both farming practices of conventional and conservation tillage systems. A total of 370 farmers were selected for the study based on the Krejcie and Morgan (1970) sampling table via a random sampling method. The research instrument was a self-made questionnaire, of which the validity was approved by a panel of experts; while the pretest-posttest method was utilized to secure its reliability. Due to the nature of questions and low literacy level of the participants, questionnaires were filled through face to face interviews by trained staff in order to collect more robust data. The comparison criterion for ecological sustainability in this study was the global hectares in which each hectare of land had the ability to absorb 1.8 tons of carbon (Guzman *et al.*, 2013). When the ecological footprint of agriculture is more than the stated amount, it is considered environmentally unsustainable. The ecological footprint model has been developed and evaluated for comparing the sustainability of conventional and conservation tillage systems based on energy consumption by using place-oriented method proposed by Kissinger and Gottlieb (2012) and Guzman *et al.* (2013) as shown below.

Table 1. Hamedan's annual cropping plan of wheat in 2013-2014.

Counties	Irrigated wheat (ha)			Rain-fed Wheat (ha)			Total		
	Planned cultivation area	Implemented	Percentage	Planned cultivation area	Implemented	Percentage	Planned cultivation area	Implemented	Percentage
Hamedan	8900	10000	%112	45500	45500	%100	54400	55500	%102
Malayer	8600	8600	%100	30000	30000	%100	38600	38600	%100
Nahavand	14200	14000	%99	9000	9000	%100	23200	23200	%99
Toyserkan	5800	5800	%100	5500	5500	%100	11300	11300	%100
Asadabad	10700	12536	%117	11000	10300	%94	21700	22836	%105
Bahar	7900	8200	%104	32000	30700	%96	39900	38900	%97
Kaboodahang	8200	8100	%99	95000	95000	%100	103200	103100	%100
Razan	16000	16000	%100	65000	65000	%100	81000	81000	%100
Famenin	5200	6000	%115	34000	34000	%100	39200	40000	%102
Total	85500	89236	%104	327000	325000	%99	412500	414236	%100

Source: Hamedan Jihad of Agriculture Organization (2014).

$$EF_t = \sum_{i=1}^{n} EF_i = \left(\frac{E_i * T}{C_o} \right) \quad (1)$$

$$E_i = F_i * EQF * 1000 \quad (2)$$

$$T = \left(\frac{P_c}{C_c * O_C * K} \right) \quad (3)$$

Where, EF_t is ecological footprint in terms of global hectares; F_i is factor of i component; E_a is energy i component in kJ, EQF_i is equivalent factor for i component; E_c is ability to generate energy per gram of coal (20 kJ), O_c is percentage of coal output by plants (0.314%) in grams; P_c is percentage of the carbon in coal (85%) in grams; K is constant coefficient to convert grams to tons (1000, 000), and C_o is the ability of a hectare of land to absorb carbon in tons (1.8 tons, Guzman *et al*., 2013)

In this model, Equivalence Factors (EQF) were used to convert effective land in global hectares (gha) proposed by Anielski and Wilson (2010) shown in Table 2.

RESULTS

EF Evaluation in the Conventional Tillage System

The ecological footprint in terms of energy consumption was derived from environmental indicators such as seeds, chemicals, fertilizers (nitrogen, phosphorus), fuel, electricity and labor estimated for conventional and conservation tillage systems shown in Table 3. According to this model, the ecological footprint related to irrigated wheat production was estimated at 2.96 of gha. The fuel component (gas oil and electricity) with more than 53 percent had the greatest impact on ecological footprints in this system. The following model demonstrates the ecological footprint of conventional tillage systems. (see Equation 4)

EF Evaluation in the Conservation Tillage System

The model below shows the ecological footprints of tillage farming practices. According to this model, the ecological footprint related to wheat production equals 2.84 global hectares (see Table 3). The fuel component (gas oil and electricity), with over 51 percent, had the greatest impact on ecological footprints. The following model demonstrates the ecological footprints of conservation tillage systems. (see Equation 5)

Independent sample *t*-test was used to compare the conventional and conservation tillage systems. The results showed that there was a significant difference between ecological footprints of the conventional and conservation tillage systems (see Table 4). It seems that the conservation tillage system was more sustainable than the conventional cropping system.

$$EF_{Conventional} = \sum_{i=1}^{5} EF_i = \left(\frac{39372.78MJ * 1000 * \left(\frac{0.85}{20 * 0.314\% * 1000{,}000} \right)}{1.8_{tons}} \right)$$

$$EF_{Conventional} = \left(\frac{39372780kJ * 0.000{,}000130}{1.8_{tons}} \right) = 2.96 gha \quad (4)$$

$$EF_{Conservtion} = \sum_{i=1}^{5} EF_i = \left(\frac{37833.18MJ \times 1000\left(\frac{0.85}{20 \times 0.314\% \times 1000{,}000}\right)}{1.8_{tons}} \right)$$

$$EF_{Conservation} = \left(\frac{37833.18kJ \times 0.000{,}000130}{1.8_{tons}} \right) = 2.84\,gha \qquad (5)$$

Table 2. EQF for inputs and outputs used in the production of irrigated wheat.

Component	Unit	Equivalent factor	Source
Wheat	kg	15.7	Tipi *et al.* (2009)
Labor	hour	1.96	Ozkan *et al.* (2004)
Nitrogen	kg	60.6	Akcaoz *et al.* (2009)
Phosphorous	kg	11.1	Akcaoz *et al.* (2009)
Potassium	kg	6.7	Akcaoz *et al.* (2009)
Gasoil	liter	38	Kaltsas *et al.* (2007)
Petrol	liter	37	Kaltsas *et al.* (2007)
Electricity	kw.h	12.1	Kaltsas *et al.* (2007)
Herbicides	kg of active ingredient	278	Tzilivakis *et al.* (2005)
Fungicides	kg of active ingredient	99	Strapatsa *et al.* (2006)
Pesticides	kg of active ingredient	237	Tzilivakis *et al.* (2005)
Wheat	kg	14.7	Tipi *et al.*, (2009)
Straw	kg	9.25	Tabatabaeefar *et al.* (2009)

Table 3. The ecological footprint of tillage systems.

Variables		Energy (MJ)[a]		Percentage		Footprint (gha)[a]		Percentage	
		A [b]	B [c]	A [b]	B [c]	A [b]	B [c]	A [b]	B [c]
Seed		3807.88	3805.5	9.67	10.06	0.29	0.28	9.80	9.86
Labor		254.8	235.2	0.65	0.62	0.02	0.02	0.68	0.70
Fertilizer	Nitrogen	12726	12726	32.32	33.64	0.96	0.96	32.43	33.80
	Phosphorous	1054.2	1054.5	2.67	2.79	0.08	0.08	2.70	2.82
Chemical pesticides and herbicides		475.2	475.2	1.21	1.26	0.04	0.04	1.35	1.41
Fuels	Gas oil	17860	16340	45.36	43.19	1.34	1.22	45.27	42.96
	Electricity	3194.4	3194.4	8.11	8.44	0.24	0.24	8.11	8.45
Total		39372.78	37833.18	100	100	2.96	2.84	100	100

[a] The energy of each component and its footprint was estimated for a hectare. [b] Conventional system, [c] Conservation.

DISCUSSION

Ecological Footprint Analysis

The results showed that the ecological footprint (gha) in the conventional tillage was higher than the conservation system. It was 2.96 and 2.84 ton per hectare in the conventional and conservation farming systems; respectively, far beyond the ecological capacity needed to absorb environmental pollution in one hectare of productive land in wheat production considered to be 1.8 global hectares. As a result, in none of the above systems wheat production was environmentally sustainable. In other words, each system needed an area equivalent to 0.64 and 0.57 of hectares more land in order to absorb the 1.16 and 1.04 tons per hectare of environmental pollution, respectively. In general, as the results were based on *EFA* with regard to energy consumption, it indicated that the

[DOR: 20.1001.1.16807073.2015.17.6.21.2]

Table 4. Independent sample *t*-test of conventional and conservation tillage systems. [a]

Tillage systems	Mean	SE	*t*	Sig
Conventional	2.95	0.02	2.94	0.003
Conservation	2.85	0.02		

[a] Levene's test for equality of variances: F= 0.022, Sig= 0.883.

environmental impact of conventional system was higher than the conservation system. Meanwhile, the conventional cropping system had less energy efficiency compared to conservation tillage system. The findings of the study are consistent with previous studies on the sustainability of conservation tillage systems undertaken by Gan *et al*. (2011), Cheng *et al*. (2011), and Knudsen *et al.* (2013).

High ecological footprints in the traditional system often results from higher usage of machinery fuel in land preparation stage of wheat cultivation. However, less machinery traffic, higher speeds, and lighter gears in conservation system reduces fuel consumption. This has led to a reduction of environmental pollution and has improved the ecological footprint of wheat per hectare (gha). In fact, the main difference in energy consumption could be summarized in fuel consumption. Among the factors related to wheat production in Hamedan Province, like many other studies (Galli *et al.*, 2014; Gan *et al.*, 2012; Xu *et al.*, 2013), fuel consumption had the highest energy consumption, and eventually the highest ecological footprint. However, contrary to previous studies (Phong *et al.*, 2010; Dong *et al.*, 2013; Crishna, 2007), energy consumption of fertilizers (nitrogen and phosphorus) were higher than fuel. It might be due to aging diesel machinery and pumps used in cultivation and irrigation which are highly polluting.

Thus, it is necessary to replace current pumps with electric ones that are less polluting. It is worth noting that although the conservation tillage system reduced environmental pollution, the estimated ecological footprints were still worrying.

CONCLUSIONS

Based on findings of this study, it can be concluded that modernization theory as a dominant notion has established in the farming systems of the study area. Hence, soil, land, and other inputs have been exploited without considering their externalities. In other words, the investigated area was strongly affected by the farmers' excessive use of chemicals (fertilizers and pesticides), high yielding varieties, cultivation and harvesting machineries. Farmers, with the aim of gaining higher profits, have continuously destroyed their environment. So, most of the prevailing farming practices were unsustainable, even those that stressed conservation farming methods. It seems that the popular conservation farming was more a fantasy and symbolic action. Because of the fact that energy, land, and water resources in most farms were being misuse and overused, resource management must become a dominant notion and planning priority for practitioners and actors. As sustainability in itself has a holistic nature, efficient management of farm resources would require economic, social, and environmental externalities to be considered in all management alternatives. This implies consideration of technical, economic, social, institutional, and environmental issues in line with participation of all stakeholders in the decision-making process. Endogenous agricultural developments in general, and participatory approaches in particular, are to be recommended. They have been developed to empower farmers by inducing positive change

[DOR: 20.1001.1.16807073.2015.17.6.21.2]

in harmony with the ecological capacity. Local NGOs, self-help groups and/or producer organizations, and local stakeholders need to become more involved in agricultural management structure, from diagnosis and policy formulation to application of farming practices. Participatory approaches will hopefully lead to a decision-making structure that is more informed and equipped to resolve problems; and consequently more accountable. Iranian ministry of Jihad of Agriculture should prepare a comprehensive and detailed plan on administrative and technical aspects of achieving sustainable development in agriculture. In this proposed plan, optimizing scheme for better use of pesticides and fertilizers, increasing performance and safeguarding the environment by using sound technologies (organic-based, ecologically sound manure system and internal input) will be necessary to maintain soil productivity for the future. , however in agricultural sector coerce regulations on "sustainable management and use" of resource not applicable.

Therefore, extension systems would have a critical role to play in transferring appropriate technologies, helping farmers learn the importance and know-how of sustainable land, soil, and water utilization practices, and then maintaining the natural resources. Meanwhile, most farmers are not sufficiently aware of their actions' consequences. Farmers declared low-tillage direct seeding machines to be very expensive and difficult to find in the local market. Diversification of rural economy (such as introducing off-farm businesses) is another complementary recommendation that could be offered to prevent excessive degradation of soil resources.

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ارزیابی پایداری نظام زراعی کشت در استان همدان براساس تحلیل ردپای اکولوژیک

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چکیده

تحلیل ردپای اکولوژیکی در کشاورزی موضوعی جدید و در حال تکامل است. این شاخص میزان زمین مولد مورد نیاز برای جبران اثرات زیست محیطی ناشی از فعالیت های مختلف کشاورزی را مشخص می سازد. در این مطالعه برای نشان دادن واحد ردپای اکولوژیک از روش هکتار جهانی (gha) استفاده شده است. این روش یک واحد مشترک و استاندارد برای مقایسه معنی داری ردپا در زمینهای متفاوت در سطح جهان است که در این مطالعه با هدف مقایسه ردپای اکولوژیکی در شیوه های زراعی مرسوم و خاکورزی حفاظتی در استان همدان مورد استفاده قرار گرفته است. برای سنجش پایداری در این تحقیق، با در نظر گرفتن مصرف انرژی، از شاخص های زیست محیطی؛ مصرف بذر، سوخت، نیروی انسانی، سموم، تولید محصول(گندم) و زائدات استفاده شد. معیار مقایسه پایداری نمره کل اکتسابی وزن داده شده (هکتار جهانی)حاصل از برآورد مدل ردپای اکولوژیکی در هر یک از شیوه های زراعی بود. رویکرد غالب این پژوهش پیمایشی بود و داده ها با استفاده از پرسشنامه و بهره گیری از روش نمونه گیری خوشه ای چند مرحله ای به صورت مقطعی در سال زراعی ۱۳۹۳-۱۳۹۲ از ۳۷۰ نفر بهره برداران عضو تعاونی های تولید کشاورزی گردآوری و مورد تجزیه و تحلیل قرار گرفت. نتایج

[DOR: 20.1001.1.16807073.2015.17.6.21.2]

تحقیق نشان داد که تفاوت معناداری بین نمره کل ردپای اکولوژیکی بر حسب هکتار جهانی در شیوه زراعی مرسوم(۲,۹۶) و حفاظتی(۲,۸۴) وجود داشت، به طوریکه شیوه زراعی حفاظتی از پایداری زیست محیطی بیشتری برخوردار است. با توجه به فاکتور هکتار جهانی، هر دو شیوه زراعی بیش از توان اکولوژیکی یک هکتار زمین مولد مورد نیاز برای جبران اثرات زیست محیطی، از زمین بهره برداری می نمایند، بنابراین بر اساس رویکرد جهانی ردپا، هر دو شیوه زراعی ناپایدار محسوب می شوند. ردپای اکولوژیکی فاکتور سوخت در هر یک از شیوه مرسوم و حفاظتی به ترتیب برابر با ۴۹,۷ و ۴۷,۲۲ درصد هکتار جهانی، بیشترین تاثیر را بر پایداری زیست محیطی داشته است. شیوه خاکورزی حفاظتی توانسته است مقدار کمی از میزان آلودگی های زیست محیط را کاهش دهد، اما میزان ردپای برآورده شده براساس هکتار جهانی رقمی نگران کننده است. رفع این چالش نیازمند یک عزم ملی است، که بدون دخالت دولت امکان پذیر نخواهد بود.