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Survey of mechanization effects on agricultural sustainability in Iran: a case study, wheat and chickpea farms in Kuhdasht County

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ABSTRACT

Agriculture provides a variety of societal functions. Intensive and expanded using of farming land in recent decades has negative effects on ecological factions and stability of their production. Mechanization is one of the main factors of modern agriculture and directly and indirectly is related to sustainable agriculture. In this study, the relationship between mechanization and sustainability of dry farming wheat and dry chickpea farms in the Kuhdasht county of Iran were investigated. Indicators in two categories: direct (energy consumption, soil compaction and air pollution) and indirect (risk of contamination with chemicals) were evaluated. The impact of mechanization indicators on social- economic (employment, job damage and economic performance) were investigated. Although these indicators do not show a complete overview of sustainability farm, for comparison, farm stability and improvement farm sustainability are effective. The results show strong communication between mechanization and the sustainability in dry farming of wheat and chickpea and although mechanization has the positive effects on sustainability but it has negative effects as well. With determining of type and scale of local mechanization, sustainability of production will increase.

Introduction

Irregular increasing of population, changing nutritional habits (Bayramoglu and Gundogmus, 2009), pollution of underground water (Babiker et al., 2003), air pollution, acid rain, destruction of ozone layer, global earth warning (Kalogirou, 2004), climate change (Johansson and Lundqvist, 1999), soil pollution (Franssen et al., 1997) and deplete of some natural sources (Bauer and Bereczky, 2003; IEA, 1998) some environmental crises that word is facing with.

Concerns about the negative impacts of economic development on human beings, communities and the natural environment made the concept of sustainable (WCED, 1987). Sustainable development is a development that provides today's needs by using of sources and environment without making any damage to them. In addition, it guarantees the production and using of resources in future (The Institute for Research and Innovation in Sustainability, 2003).

Concept of sustainable development is related with social-economic themes and environmental phenomena by using evaluation and pressure indicators (DETR, 2000; OECD, 2000). Perman et al (1999) introduce the concept of sustainability as development guidance and expressed that deciding and choosing technology must be on the basis of it, they expressed that sustainability needs without damaging environment. Agriculture plays different social roles. These roles not only terminate to food production and other initial raw materials but also, interfere in providing ecological sources like drinkable water and biological variation. Intensive and expanded using of farming lands in the recent decades affected the ecological operation and ecology in most of regions and lands. Therefore, for reaching the sustainable development of farming, the environmental programming must not be included just ecological problems, but also It is included the economic and social problems (Ahrens and Kantelhardt, 2009). Modern agriculture depends on mechanization incisively and instruments, tools, power recourses and management processes related to it, are used in production of foodstuffs and non-foodstuff. Farm's mechanization includes organized hardware and software parts of mechanized systems and the main method for transportation and movement in farms have included of work on soil, cultivation of plant, application of herbicide and pesticide and harvest and directly and indirectly is related with sustainability (Leiva and Morris, 2001) (Table 1). Mechanization has effects on environment with making pollution (Court et al., 1995) and changes earth's management and consequently changes soil, water quality, inhabitants and biological variation, wildlife, earth's perspective and compatibility of it. Mechanization is the most consumer of nonrenewable energy (Stout, 1990) and it is the most important factor in irrigation of farms. In addition, the health of people that works with machine is in danger (Monk et al., 1986).

Mechanization of farms affect social problems and causes decreasing of employment in village and farms, integrating of farms and renting of farms and in view of economic can include more share of farming cost (Pretty,1998), however, if Mechanization selected and managed appropriately, can help to improve the degree of sustainability of farming (Leiva and Morris, 2001).

The aims of this study is consideration of mechanization's relationship with sustainability in farms under cultivation of dry farming chickpea and wheat in Kuhdasht county of Iran and evaluation of sustainability improvement with changing of mechanization's technology and related operation to it.

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Indicators of mechanization effects and their relationship with agriculture stability

Indicators are classified in three groups that have various relationships with mechanization. In most of cases, these indicators don't show the overview of sustainability but are appropriate for comparison among farms (Leiva and Morris, 2001).

Indicators that show the direct effects and pressures of mechanization

Energy

Nowadays, agricultural sector has become more energy-intensive in order to supply more food to increase population and provide sufficient and adequate nutrition. However, considering limited natural resources and the impact of using different energy sources on environment and human health, it is substantial to investigate energy use patterns in agriculture (Hatirli et al., 2005). Energy ratio (total output energy to total input energy), net gain energy (total output energy- input energy), energy productivity (yield to input energy) and intensity of energy (total output energy to yield) are proper indicators for comparison the operations and productive systems (Esengunm et al., 2007).

Air pollution

Combustion of fossil fuels cause pollution which are resulted of NOx, SO2, CO2 and other gases that has much effect on environment like, creating acidic raining, air pollution, demolition of Ozone layer, demolition of earth and global warming (Kalogirou, 2004). In 2002, air pollution cost in Iran included 1.6% of grass net production (1810 million dollars of American) and emission cost of CO2 1.6% of grass net production (World Bank, 2005).

Risk of soil compaction

Keeping of proper ratios among solid, liquid and gas phases of soil has special importance. These ratios are obtained just in some soils and in special continental conditions and human's correct activity. Solid phase of soil in fixed volume will increase and gas phase will decrease by entering of machine to farm. However, increasing of farming machinery capacity has had advantages but it has caused soil compaction and has had negative effects on production of farming crops. The most destructive effect of crossing farming machinery in farms is pressing of soil. Pressed soil can cause intensive negative effects in production of farming crops that the reason for this problem is nutrient exiting in plant's accessibility (Vaz, 2003). Compaction increase causes to decrease in pores of soil, soil ventilation and its Oxygen and increase carbon Dioxide and these changes cause negative effect on plant growing. In addition, this compression will cause resistance increase to influence of soil and growing of plant root faces with problem that if this resistance be more than growing strength, growing of it will stop (Chen et al., 2005).

Indicators that show the indirect effects and pressure of mechanization

These indicators are in communication with application and using of mechanization as an agent of modern farming practice. The indicators are important components of sustainability of farming land.

Risk of nitrate leaching

Underground waters are proper storage for world drinkable water because of its purity and cleanness. Underground waters constitute almost 68% of world fresh waters. Therefore, keeping underground waters from pollution resources is very important (Babiker et al., 2003). After pesticides, Nitrate has the most important role among chemical pollutions of underground waters in world (Bachmat,, 1994; Spalding and Exner, 1993). Nitrogen is a key element in plants nutrition, but incorrect consuming of it with nitrogen transfer from farming lands to underground waters have caused pollution of underground waters to nitrogen (Hudak, 2000; Levallois et al., 1998).

Risk of pesticide pollution

Consuming of pesticide has many profits in farming but pollution of environment, foodstuff and drinkable water by pesticide are other problems about pesticides. For evaluating risk pesticide pollution, leaching to underground waters, durability and poisonousness of it are applied (Leiva and Morris, 2001). Other risks associated with mechanized pesticide application include eco-toxicity impacts on sensitive natural species (Campbell and Cooke, 1995). Incorrect methods of spraying pesticide, damage to people's health (who sprayed or who is exposed in air draft of pesticide). In addition, residue of pesticide in foodstuff can threaten human's health by using of improper dosage of pesticide. These factors increase the risk of society's health (Baldock and Bishop, 1996).

Organic materials of soil

This was evaluated with percentage of organic carbon and percentage organic materials in surface soil. The ratio of organic carbon to organic materials of soil is 1 to 1.7 (Brady, 1995; Leiva and Morris, 2001).]

Indicators that show social- economic effects of mechanization

Most of time, there are a communication between mechanization of farms and social- economic cases.

Social sustainability

Mechanization effects on social sustainability such as of employment, health, safety and environmental indicators in farms and changes them (Leiva and Morris, 2001).

Financial performance

Mechanization affects the production costs of farms, changes income and benefit of farms. From a financial viewpoint, farm mechanization accounts for about 30% of all on-farm costs (Leiva and Morris, 2001).

Introduction of region under study

The Kuhdasht County is located in the west of Iran, within 47° 39' north latitude and 33° 31' east longitude. It is a semiarid region in west of Lorestan province and its high from sea level is 1198 meters. The average of annual rainfall of it is 405 mm, the minimum and maximum temperature is -20.6 c° and 43 c° respectively (Iran meteorological organization, 2009). The level under cultivation of chickpea and wheat in Kuhdasht County are respectively 14000 and 51000 hectares and is accounted one of production's poles of chickpea and wheat in Lorestan province (Statistics Annuals of Lorestan Province, 2009).

Materials and methods

From point of purpose, this research is an applied research and from point of gathering of data is a kind of field researches. The statistic population of this study has been farmers that plant dry farming chickpea and wheat in Kuhdasht. At first 30 questioners distributed among farmers that plant dry farming chickpea and 30 questioners distributed among farmers that plant dry farming wheat, and then sampling volume is evaluated by using of equation (1) (Yamane, 1967). Data were collected 68 and 57, respectively dry farming of chickpea and wheat farmers. This sample size was determined using a stratified random sampling technique.

$$n = (\sum N_h S_h)/(N^2 D^2 + \sum N_h S_h^2) \quad (1)$$

Where n is the required sample size; N is the number of holdings in target population; Nh is the number of the population in the h stratification; Sh is the standard deviation in the h stratification, is the variance of h stratification; d is the precision where (-); z is the reliability coefficient (1.96 which represents the 95% reliability); .

For the calculation of sample size, criteria of 5% deviation from population mean and 95% confidence level were used.

Input and output energy express in form of equal energy of them in quantity of MJha-1. Input energy includes energy of labor, machines, diesel fuel, seed, fertilizer and pesticide. Energy equivalents coefficients were used for accounting of input and output energy. Output energy contains equal energy of grain and straw of wheat and chickpea. The input energy was divided into renewable and non-renewable forms. Non-renewable energy includes diesel, pesticide, fertilizers and machinery, and renewable energy consists of human labor and seeds.

CO2 emission from aisle fuel and NOx of diesel fuel and nitrate fertilizer are used as indicators that are a risk for air pollution. CO2 emission rate is 3.6 kg of each liter of diesel fuel (Taylor et al., 1993) and NOx emissions rate from diesel fuel in farming, accounted 16 g L-1 is basis of energy balance- sheet of Iran and emission rate of it from nitrate fertilizer is equal to 1.57% of nitrate fertilizer for wheat in winter (Cole et al., 1996). The amount of emission of CO2 and NOx accounted in multiplication of diesel fuel consuming amount and nitrate fertilizer in their coefficients.

Soil compaction depends on the rate of machines crossing and their weight. The equation 2, 3, 4 are used for evaluation of this factor (Leiva and Morris, 2001).

$$A_c = \frac{\omega}{w} \quad (2)$$

Ac is the whole percentage of land that is covered by rear wheels track of tractor and by considering whole farm's operations. The contact width ω was assumed 87% of the overall width of the tire and w is the operational width of the implement in m. This indicator shows the coverage rate of land by wheel but does not express the real risk of soil compaction properly.

The soil indicators that obtain of contacts pressure in quantity of kilopascal expresses better the soil compaction risk.

$$I_L = 10\frac{P}{w} \quad (3)$$

$$I_A = PR_T \quad (4)$$

Where: IL is the compactness indicator for length in kPa km ha-1; IA is the compactness indicator for time in kPa h ha-1; and RT is the theoretical time for the operation in h ha-1. Contact pressure was assumed equal to the inflation pressure of tires.

The amount of nitrate leaching is accounted in quantity of mg L-1 and it is applied for risk of nitrate leaching. The amount of nitrate leaching is dependent to kind of soil, amount of rainfall, management, method and average of fertilizing. In farming, the scale of nitrate leaching is accounted in quantity of kg ha-1 in year (Jones and Thomasson, 1990). Because in Iran, there are no exact researches in this case, farms of a region are considered. The amount of nitrogen fertilizer consuming is used for comparison of nitrate leaching risk to underground water in two type farms.

Except north region of Iran, The amount of organic material of soil is very low and soil is very poor in viewpoint of organic materials (less than 0.5%) (Minister of agriculture Jihad, 2009). So, for this reason, the accounting of organic materials of soil relinquished.

Employment is accounted in form of labor- hour in hectare in plant season and for evaluating of health and safety in farms, number of events and harms in communication to agricultural machinery and environmental events that has taken place in recent 2 years, is taken into consideration.

Net income and gross income of each hectare is used for evaluation of economic operation. Production costs include costs of seed, fertilizer, pesticide, diesel fuel, machine, labor and opportunity cost of land. The rental cost in region is used for accounting of machinery costs. Labor and land cost are taken into consideration equal to their opportunity cost. The wage average of labor in the region is taken into consideration its opportunity cost and opportunity cost of land is equal to its rental cost in region. Income includes of obtained value of grain and straw of crops.

Research and discussion

The results of measuring the sustainable indicators in both of two crops are shown in Table 4. Input and output energy obtained in dry farming wheat more than dry farming chickpea (Table 2 and 3). Having more energy ratio, productivity, net gain energy and also having less in the intensively of energy show that in addition to more production of energy in dry farming wheat, in lieu of energy unite in it is accounted more than production of dry farming chickpea in region. About 78% of input energy in dry farming wheat and about 76% of input energy in dry farming chickpea is nonrenewable.

The fuel consuming in dry farming wheat and chickpea is 39% and 55%, respectively but the CO2 emission in wheat farms is more than chickpea (Table 4) because of more consuming of diesel fuel in these farms. Emission of NOx in dry farming wheat farms is more because of more nitrogen fertilizer and diesel fuel consuming. Therefore, the risk of air pollution in wheat farms is more.

The risk of soil compaction in dry farming wheat farms is more than dry farming chickpea because of using more of machinery for operation. In producing of dry farming chickpea, consuming of nitrogen fertilizer is not ordinary but it is common in production of wheat. Therefore, the risk of nitrate leaching is more in dry farming wheat farms. Consuming of pesticide is very much in production of chickpea that has been poisonous for useful insects and causes their annihilation and lack of subsistence balance.

Dry farming wheat production is more efficient in viewpoint of economic. The main reasons of it are large dry farming wheat farms and their mechanized cultivation that have decreased labor cost. Net income of dry farming chickpea production has been negative that having high manual operations (for reason of manual and traditional farming of chickpea) and high cost of labor and low production of this crop have caused this affair but most of labors are domestic and farmers don't consider it as a cost, they still continued to produce dry farming chickpea. Labor and machinery include respectively of 63.5% and 9% of total production cost of dry farming chickpea and 15% and 24% of total production cost of dry farming wheat. The average of land size of dry farming chickpea is 4.35 hectares but the average of each plot size of cultivation is about 1.8 hectares just for the reason of not being integrated farms. The average of land size of dry farming wheat is 8.4 hectares but the average of each plot size of under cultivation is about 3.2 hectare. In production of dry farming chickpea and wheat are respectively about 71% and 64% tractor and equipment inform of rental, 24% and 33% private and 5% and 3% in form of partnership and cooperative services. The average of labor in each hectare for dry forming chickpea is 7.5 times of wheat because of traditional cultivation and more manual operation. 78% of chickpea farms are private and the rest are in form of sharing. Sharing is in this form that 1/3 of crop will belong to the owner. In production of dry farming wheat 97% of farms are private and the rest are rental. About of 61% of farmers that plant dry farming wheat just to farming and the rest, in addition to doing farming do animal husbandry too. Dry Farming wheat in this region is in form of mechanization and the labor more is the operator of tractor and agriculture instrument.

Dangers and injuries of machines are more in production of dry farming wheat and job damages have been more intensive so that this subject is in relation with mechanized cultivation of this crop and lack of observing safety principals and necessary training in communication with machinery.

Consuming of diesel fuel is the most consuming energy in production of two crops. Diesel fuel is nonrenewable energy and combustion of it is the main factor of air pollution.

Plowing with Chisel plow preserves structure and moisture of soil in addition to in fuel consuming and decrease soil compaction. Other factors of fuel and risk of decreasing soil compaction are adjusting of equipments, using of modern technology and proper methods.

Nitrate fertilizer must consume in form of top dressing and by considering to weather and rainfall condition that be used efficiently and risk of leaching to underground waters decreases. Consuming of pesticide is a lot in dry farming chickpea. Consuming of pesticide, air draft risk and residue of it in foodstuff can be decreased by using of proper technology and methods of spraying of pesticide.

Dry farming chickpea production is not economic efficiently and labor cost is of high importance. However, mechanized operation of dry farming chickpea production causes to decrease in labor and economic costs but it causes to decrease employment and creating of social problems in region. Therefore, Scale of mechanization of dry farming chickpea farms operation must be determined by exact study and be performed on basis of it.

Conclusion

In this study, the relationship between mechanization and sustainability of dry farming wheat and dry chickpea farms in the Kuhdasht, Iran were investigated. Indicators in two categories: direct, indirect and social- economic were evaluated. Data were collected from 68 and 57 dry forming chickpea and wheat farms, respectively, which were selected based on random sampling method.

In viewpoint of sustainability, indicators of energy, risk of pesticide pollution and finance performance in dry farming wheat are better than dry farming in chickpea but indicators of risk of air pollution, risk of soil compaction, pollution of nitrogen fertilizer and safety are better in chickpea. With determining of type and scale of local mechanization, sustainability of production will increase.

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Table1. Issues and themes for agricultural policy and links to farm mechanization

Links to farms mechanization	Themes	Issues
Application technologies and soil management, especially cultivation systems	Nutrient losses to freshwater; soil P levels; nutrient management practices	Nutrient use
Application technologies and practices, including risk of spillage/drift, residues in food and food safety	Pesticide use	Pesticide use
CO_2 and NO_x emissions from fuel use	Greenhouse gas emissions	Greenhouse gases
Mechanized irrigation supply and application systems	Water use	Water use
Agri- chemical contamination risks associated with application methods		Water quality
Organic matter content and compaction risks associated with mechanized soil management practices and field operations	Soil protection	Soil quality
Areas (*e.g*. field margins) and features (*e.g*. hedgerows) of conservation interests affected or managed by mechanized systems, mechanization of organic crop production, agricultural cropping systems and field patterns, mechanized land restoration, *e.g*. land fill or mineral sites	Conservation value of agricultural land	Land use and conservation; landscape; bio-diversity; wildlife habitats
Adoption of environmental management systems by farmers, including mechanization performance and impacts	Environmental management systems	Farm management
Association between mechanization, incomes, employment, skills, health and safety, and the structural characteristics of the farming sector	Rural economy	Socio-cultural issues; farm financial resources
Energy consumed by farm mechanization, opportunities for mechanized production of energy crops	Energy	

Reference: (Leiva and Morris, 2001)

Table 2. Inputs and outputs for dry farming wheat production

item	Value	Energy equivalent (MJ unit^{-1})	Energy MJ ha^{-1}	Energy %
input				
labor	31.7 (h ha^{-1}) †	1.96 (MJ h^{-1})	62.1	0.6
Diesel fuel	82.8 (L ha^{-1}) £	47.8 (MJ L^{-1})	3957.8	39
Machinery and equipment	€	€	599.5	6
Phosphorus fertilizer, [P_2O_5]	28.11 (kg ha^{-1}) £	17.4 (MJ kg^{-1})	489.1	4.8
Nitrogen fertilizer (N)	36.5 (kg ha^{-1}) £	78.1 (MJ ha^{-1})	2850.65	28.1
seed	147.5 (kg ha^{-1}) †	14.7 (MJ kg^{-1})	2168.3	21.35
pesticide	0.18 (kg ha^{-1}) £	85 (MJ L^{-1})	15.3	0.15
Output				
grain	565.65 (kg ha^{-1}) †	14.7 (MJ kg^{-1})	26166	66
straw	648.6 (kg ha^{-1}) †	12.5 (MJ kg^{-1})	13375	34

£: [34] ,€:[26], †: Their equal energy is accounted separately for machinery in basis of £ resource and their sum are brought.

Table 3. Inputs and outputs for dry farming wheat production

item	Value	Energy equivalent (MJ unit^{-1})	energy MJ ha^{-1}	energy %
input				
labor	207.62 (h ha^{-1})	1.96 (MJ h^{-1})	406.9	9
Diesel fuel	51.4 (L ha^{-1})	47.8 (MJ L^{-1})	2457	54.6
Machinery and equipment	€	€	375.6	8.3
Phosphorus fertilizer, [P_2O_5]	27.1 (kg ha^{-1})	17.4 (MJ kg^{-1})	471.5	10.5
seed	44.97 (kg ha^{-1})	14.7 (MJ kg^{-1})	661.1	14.7
pesticide	0.43 (kg ha^{-1})	295 (MJ L^{-1})	126.9	2.8
Output				
grain	565.65 (kg ha^{-1}) †	14.7 (MJ kg^{-1})	8318	51
straw	648.6 (kg ha^{-1}) †	12.5 (MJ kg^{-1})	8107.5	49

Table 4. Result of sustainability indicators for farm mechanization

Component	Indicator	Estimates for the study forms: Dry farming chickpea	Estimates for the study forms: Dry farming wheat
Energy	Input energy	4499	10121
	Output energy	16426	39541
	Energy productivity	0.27	0.28
	Energy intensity	3.7	3.55
	Net gain energy	11924	29420
	Energy ratio	3.65	3.91
Air pollution	CO2 of diesel fuel, kg ha^{-1}	185	298.1
	NO_x of diesel fuel and N fertilizer, kg ha^{-1}	0.8	1.87
Soil compaction	covered by wheel, %	216	252.5
	Wheel intensity, t km ha^{-1}	75.75	116.65
	Field load intensity, t h ha^{-1}	17.2	27.1
	Compactness, kPa km ha^{-1}	863.5	1631.8
	Compactness, kPa h ha^{-1}	168.8	319.2
Consume of N fertilizer	Kg ha^{-1}	0	36.5
Consume of pesticide (active material)	L ha^{-1}	o.43	0.18
Health and safety and environmental incident on farm	Number of injury that took place in communication with machinery (%)	4	8
	Injury number of environment incident	0	0
Labor employment	Labor – day per hectare	30	4
Financial performance	Gross income (USD per hectare)	397	745
	Net income (USD per hectare)	-18	389