CALCULATION OF ENERGY REQUIREMENT AND ENERGY EFFICIENCY FOR PRODUCTION OF MAJOR AGRICULTURAL CROPS

Ahmad Gholami[1] and Saeed Sharafi[2]
[1]Department of Agronomy, Shahrood University of Technology, Shahrood, Iran
[2]Department of Agronomy, Arak University, Arak, Iran
E-Mail: ahgholami@yahoo.com

ABSTRACT

This study was carried out to determine the energy use in the Iran agricultural sector for the period of 1980-2005 to evaluate the impact of energy input to produce output. The inputs in the calculation of energy use include human labor, machinery, electricity, fertilizers, seeds and output energy included 16 agricultural crops yield. Energy values were calculated by multiplying the amounts of inputs and outputs by their energy equivalents with the use of related conversion factors. The energy efficiency is determined by dividing the output value by the input value. The results indicated that the total energy input increased from 55.64 $\times 10^9$ MJ/ha in 1980 to 150.71×10^9 MJ/ha in the year 2005. Similarly, total output energy rose from 325.56×10^9 to 535.15×10^9 MJ/ha in the same period. It was found that energy efficiency was declined from 5.85% in 1980 to 3.55% in 2005, which indicates that the energy input increased faster than energy output. It also indicates that the use of inputs in Iran agricultural production was not accompanied by the same results in the final product. This can lead to problems associated with these inputs, such as global warming, nutrient loading and pesticide pollution. Therefore, there is a need to choose a new policy to force producers to undertake energy efficient practices to establish sustainable production systems.

Keywords: energy, efficiency, input-output ratio, agriculture, crops, production, iran.

INTRODUCTION

Humans have found ways to secure their food from the Earth's land, beginning more than a million years ago with the hunter-gatherers. One of the major factors that caused humans to move from hunting and gathering to slash-and-burn agricultural production was the continual expansion of their population. About 10000 years ago and after human began to agricultural activity; total population on the earth was 1 million people. Once fossil energy supplies became available about 200 years ago, intensive agricultural production developed (Pimental and Pimental, 2005). The crop yield is a function of energy input. Depending on the environmental conditions, crops convert only 0.5-5% of the photosynthetic active radiation (PAR) into biomass (Hulsbergen *et al.*, 2001). Sources of energy other than solar radiation, wind, etc. were summarized as support energy (Alam *et al.*, 2005). Input of support energy into agricultural systems increase the proportion of solar energy that is captured by the plants. Support direct energy is required to perform various tasks related to crop production processes such as for land preparation, irrigation, harvest, post harvest processing, transportation of agricultural inputs and outputs. In other word, direct energy includes fuel and electricity which are directly used at farm (Hulsbergen *et al.*, 2001). Indirect energy is not directly consumed at the farm. The major items for support indirect energy are the energy used in the manufacture, packaging and transport of fertilizers, seeds, machinery production and pesticides (Ozkan *et al.*, 2004).

The input of support energy for the crop production differs to a large extent. Modern crop production is characterized by the high input of fossil energy (fuel and electricity) which is consumed as direct energy and as indirect energy (fertilizers, pesticides, machinery, etc.). In some low-input farming systems, e.g. in large areas of Africa, the energy input on arable land is lower than 1GJ ha^{-1}, whereas in some modern high-input farming systems in west Europe, it can exceed 30 GJ ha^{-1} (Hulsbergen *et al.*, 2001). At present productivity and profitability of agriculture depend on energy consumption. As a result of increasing inputs of agrochemicals and the use of more productive cultivars, crop yields increased continuously. Although contemporary, energy intensive agricultural systems are highly productive, their sustainability is questionable because: rapid population growth necessitates continued increases in the use of cropland and water resources-fossil energy (fertilizers and irrigation) resources that are essential for supplying fertilizers, pesticides, irrigation, and mechanization are non-renewable and the agricultural environment is being degraded by both soil erosion and the pollution of fresh water and biological resources (Pimental and Pimental, 2005).

Environmental problems due to intensive use of energy remain crucial, especially because of CO_2 and NO_X emission due to the fossil energy combustion. CO_2 being the major greenhouse gas and the NO_X being involved in the generation of the ozone-gap in the troposphere (Pervanchon *et al.*, 2002). The major sources of greenhouse gas emissions from agriculture include soil microbiological and chemical processes which convert organic materials into its elemental components, and the burning of fossil fuels to power machinery for soil tillage, cultural operations, drying of crops and transportation of products (Zentner *et al.*, 2004).

Stores of fossil energy also have begun to decline; this trend will intensify after the year 2000. If the world population continued to grow at a rate of 1.5% and if all people in the world were to enjoy a standard of living and energy consumption rate similar to that of the average

American, then the world's fossil fuel reserves would last only about 15 years (Pimental and Pimental, 2005). Now, at the turn of the century, we are faced with meeting the food needs of a rapidly increasing human population. Currently, more than 3 billion people in the world are malnourished due to outright food shortages and poor distribution of foods. To meet the basic food needs of increasing human population, a productive, sustainable agricultural system must become a major priority. In the past decade, with increase in energy inputs in agriculture, an equivalent increase in crop yields occurred. Other studies have suggested that the energy use efficiency of our traditional cropping systems have been trending downward in recent years due to energy inputs increasing faster than energy output as a result of the growing dependency on inorganic fertilizers and fossil fuels (Zentner *et al*., 2004). If the increase in the energy use in the agricultural industry continues, the only chance of producers to increase total output will be using more input as there is no chance to expand the size of arable lands. Under these circumstances, an input-output analysis provides planners and policy-makers an opportunity to evaluate economic interactions of energy use.

The aim of this study was to provide a descriptive analysis of energy use in Iran agriculture in the period 1980-2005. This analysis is important to perform necessary improvements that will lead to a more efficient and environment-friendly production system.

DATA COLLECTION AND METHODOLOGY

The energy ratio in Iran agricultural production was calculated for the period 1980-2005. In the calculation of the energy ratio, human, machinery, electricity, seed and fertilizer amounts and yield values of 16 crops have been used. The data were converted into suitable energy units and expressed in MJ/ha. Energy equivalents of inputs and outputs are given in Table-1 (Alam *et al*., 2005; Ozkan *et al*., 2004; Pimentel and Pimental, 2005). The data used in the study were collected from various resources (Ministry of Agriculture, Ministry of Energy and Iran Tractor Manufacturing Co). Energy ratio of input-output is determined by calculating energy equivalents yields gained from major crops produced and that consumed inputs in production (Alam *et al*., 2005; Ozkan *et al.*, 2004). In this study, 16 crops were taken into account to estimate output energy values. These crops are wheat, barley, maize, rice, lentil, chickpea, bean, sunflower, soybean, peanut, castor, canola, safflower, cotton, potato and sugar beet. The inputs used in the calculation of agricultural energy use include human labor, machinery, electricity, fertilizers, pesticides and seeds. For the estimation of energy input for agriculture, working days of agricultural workers are taken as 210 days assuming an average of 8 h of work a day (Ozkan *et al*., 2004). In the calculation of chemical energy input information on individual fertilizer used was not available; therefore, amounts of three main kinds of fertilizers (nitrogen, phosphate and potash) were used in the estimation. Amount of pesticide was also converted to energy equivalent. In order to be able to make the analysis, it is essential to consider biochemical energy sources, i.e. the amount of energy stored in the seed. Energy output from selected seeds of agricultural species was calculated by multiplying the production amount by its corresponding equivalent. To quantify the indirect energy input associated with the maintenance of the machinery, average life times of 10 years were assumed.

The energy efficiency of the agricultural system in Iran has been evaluated by the energy ratio between output and input for the period 1980-2005.

RESULTS AND DISCUSSIONS

In this study output-input energy ratio were calculated by using energy consumptions of labor, machinery, fertilizer, seeds used in mentioned agricultural production. The main physical power sources of Iran agriculture were examined and results are presented in Table-2. Inputs such as human labor and machinery used in agriculture were expressed as physical power sources. The results indicated that an increase was observed in the agricultural labor for the period under study. As can be seen in Table-1, the active agricultural population increased from 1.94 million in 1980 to 3.05 million in 2005. Similarly the total human power in agriculture increased from 2.93 million hp in 1980 to 4.61 million hp in 2005. This result indicates that an increased of about 57% occurred in the active population and total human power.

In this study we have not any documents for animal power in agriculture. The reason can be attributed to the increase observed in the level of mechanization. The number of tractors rose from 11742 in 1985 to 102682 in the year 2005 growing, at about 9-fold rate. In the study period, the total power calculated for tractors increased from 11.27×10^7 to 98.57×10^7hp. This increase can be attributed to increase in the number of tractors and the development in horse power of tractors. Total physical powers calculated for agricultural labor and machinery is given in Table 2. As can be seen, total physical power raised from $6.75\times10^{9\ \mathrm{MJ}}$ in 1980 to 12.88×10^9 MJ in the year 2005.

Input values of physical energy in agriculture are illustrated in Table-3. Total physical energy input consists of human labor, machinery power and electricity consumptions. It was observed that there was a small amount increase in the energy input value for human labor, while there was considerable increase for machinery power and electricity in the study period. The input value of physical energy was estimated to be 9.25×10^9 MJ in 1980 and it reached to 64.03×10^9 MJ in 2005. This shows that physical input value used in the agricultural industry increased about 7- fold rate. At the beginning of the examined period the shares of human, tractor manufacture, and electricity energy in total power was 73%, 2.8% and 27%, respectively. At the end of study the shares of above section was 16.57%, 3.5% and 79.9%, respectively.

In the calculation of fertilizer energy input in agricultural production, N, P_2O_5 and K_2O were taken into account and estimated values were summarized in Table-4. As can be seen from the table, there was a 2.16-fold increase in terms of fertilizer energy input for N, 1.38-fold for P_2O_5, and 7.5-fold for K_2O in 1980. Total fertilizer energy input in agricultural production was calculated as 29.83 $\times 10^9$ MJ in 1980 and it reached 62.32 $\times 10^9$ MJ in 2005.Table-5 shows that pesticide use in Iran agriculture increased from 9.27 $\times 10^6$ ton in 1980 to 55.56 $\times 10^6$ ton in 2005(about 6-fold rate). This result indicated that energy equivalent increased from 0.93 $\times 10^9$ MJ to 5.6 $\times 10^9$ MJ in the study period.

Seed use amounts, seed energy equivalent value sourced from seed use were also examined in the period 1980-2005 (Table-6). In 1980, cereal have the highest ratio in the total amount of seeds with 77%, followed by 20.5% for potato and 2.1% for pulse crop .In 2005, cereal , potato and pulse crop constitute the total amount of seed consumed with shares of 68, 26.8 and 4% , respectively. The energy equivalent value for seed use was 15.72 $\times 10^9$ MJ in 1980 and it increased to 18.76 $\times 10^9$ MJ in 2005. Total input energy increased by approximately 19.3% from 1980 to 2005.

Production values of selected crops and their energy equivalents are given in the Table-7. Total production of selected crops are as 19.55 $\times 10^6$ tons for cereal , 0.37 $\times 10^6$ tons for pulse crop, 0.17 $\times 10^6$ tons for oil seed, 3.65 $\times 10^6$ tons for sugar beet, 1.48$\times 10^6$ tons for potato and 0.19 $\times 10^6$ tons for cotton seed in 1980. In this year, the production values of cereals and sugar beet have the highest ratio with 76.9% and 14.4%, respectively. Total production value rose from 25.41 $\times 10^6$ tons in 1980 to 41.29 $\times 10^6$ tons in the year 2005. The shares of cereals, pulse crop, oil seed, sugar beet, potato and cotton seed in 2005 were 76.46%, 2.4%, 1.3%, 11.87%, 7.2% and 0.7%, respectively. The most increase over the study period was in oil seed production with 220% increase. The production value increases are 61% for cereals, 170% for pulse crop, 100% potato, 34% for sugar beet and 52% for cotton seed during the study period. Results indicate that there was increase in the output of examined crops (Table-7). Energy equivalents of examined crops were calculated by using equivalent value of each crop. The results showed that the total output energy equivalent is estimated to be 325.56 $\times 10^9$ MJ in 1980 and it has increased 535.15 $\times 10^9$ MJ in 2005 (Table-8), and this increase is realized as 64.4%. Total output energy is influenced by developed seed varieties, weather and technology. A comparison of output energy vs. input energy was performed. The energy ratio was calculated by dividing total input energy ratio into total output energy. The results of input–output values per hectare basis for Iran agriculture are presented in Table-8. As can be seen, output-input ratio has declined from 5.85 in 1980 to 3.55 in 2005. This result indicated that input energy value has shown faster increase compared to output energy value.

CONCLUSIONS

The aim of this study was to calculate the output-input ratio in Iran agriculture to explore the current and past trends in respect of energy use. The methodology used in calculation of energy use was broken down into two groups, namely inputs and outputs. The total input energy consisted of the sum of all components of energy used in production of outputs. The energy ratios in this study are based on the total input and output in the agricultural sector. The major inputs used in agricultural production and the output for the 16 crops were multiplied by their energy equivalents for the period of 1980-2005. The results showed that total input energy consumption and output energy increased during the years 1980-2005. The input energy value rose from 55.64 $\times 10^9$MJ/ha in 1980 to 150.71 $\times 10^9$MJ/ha in the year 2005. Similarly, total output energy increased from 325.56 $\times 10^9$MJ/ha in 1980 to 535.15 $\times 10^9$MJ/ha in 2005. The energy ratio was estimated to be 5.85 in 1980 and 3.55 in 2005. Hence, the energy ratio declined about 39% over the study period. It indicates a poor development in the energy use efficiency due to the decrease of the energy ratio. The reason for this results mainly from the fact that total output energy is not increasing at a faster rate than total input energy in Iran agriculture. The production area for the crops increased from 9.4 to 11.2 million hectare from 1980 to 2005. The intensive input use was not accompanied by the expected output increase. When the ratios of input energy values per hectare are examined, in 2005 physical energy value has the highest share with 42.48% followed by fertilizer energy value with 41.35%, and seed energy value with 12.45%. During the last 25 years the increase in physical input, fertilizer and seed energy input values was estimated as 6.9, 2.1 and 1.2-fold, respectively, although it has been realized as 1.6 fold for yield (output)energy value .Fertilizer represents one of the main indirect energy consumption sources. Special emphasis must be put on the energy equivalents of fertilizers, because the rate of fertilizer application has a particularly strong affects on the input energy (Clements *et al.*, 1995; Hulsbergen *et al.*, 2001; Pervanchon *et al.*, 2002). In agricultural systems, the energy intensity may be reduced by growing crops that are capable of biological N fixation. The recycling of livestock manure on the farm and the use of a cover crop are ecologically sound practices included in this sustainable system (Pervanchon *et al*., 2002; Pimental and Pimental, 2005). This result indicates that use of inputs in Iran agricultural production was not accompanied by the same results in the final product. It indicates that producers are not undertaking more efficient. Production practices and decreases in the ratio seem to be resulting from increases in inputs. This means that the use of inputs is still increasing and energy-related problems associated with agricultural production are still occurring. For this reason it is necessary to promote development of new technologies and use of alternative energy sources. It is suggested that some specific policies be taken to reduce the negative effects of energy use, such as pollution, global warming and nutrient loading. Within this framework, energy analysis is important to make improvements that will lead to more efficient and environment-friendly production systems.

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Table-1. Energy equivalents of inputs and outputs (MJ).

Human	**2.3** (MJ)	**Hour**
Electricity	11.93	kwh
Machinery	0.9	hp
Fertilizer		
N	64.4	kg
P_2O_5	11.96	kg
K_2O	7.6	kg
Seed ratio		
Cereal and pulse	14.7	kg
Oilseed	25	kg
Tubers		
Potato	3.6	kg
Sugar beet	5.04	kg

Table-2. Availability of physical power sources in Iran agriculture.

Year	**Human Number** (million)	**Av. Power** (hp)	**Total Human Power** ($\times10^6$ hp)	**Total Human Power** (MJ)	**No. of Tractors**	**Av. Power** (hp)	**Total Tractor Av. Power** ($\times10^6$ hp)	**Total Tractor Power** (MJ)	**Sum** (MJ)
1980	1.94	0.9	2.93	6.75×10^9	-	-	-	-	6.75×10^9
1985	2.16	0.9	3.26	7.51×10^9	11742	10	11.27×10^7	0.26×10^9	7.77×10^9
1990	2.38	0.9	3.59	8.30×10^9	38454	10	36.92×10^7	0.85×10^9	9.15×10^9
1995	2.60	0.9	3.93	9.04×10^9	63427	10	60.89×10^7	1.40×10^9	10.44×10^9
2000	2.83	0.9	4.27	9.84×10^9	91628	10	87.96×10^7	2.02×10^9	11.86×10^9
2005	3.05	0.9	4.61	10.61×10^9	102682	10	98.57×10^7	2.27×10^9	12.88×10^9

Table-3. Estimated physical energy input in Iran agriculture.

Year	**Total human power** (MJ)	**Total tractor power** (MJ)	**Electricity** (MJ)	**Sum** (MJ)
1980	6.75×10^9	-	2.50×10^9	9.25×10^9
1985	7.51×10^9	0.26×10^9	8.78×10^9	16.55×10^9
1990	8.30×10^9	0.85×10^9	13.37×10^9	22.52×10^9
1995	9.04×10^9	1.40×10^9	19.44×10^9	29.88×10^9
2000	9.84×10^9	2.02×10^9	32.92×10^9	44.78×10^9
2005	10.61×10^9	2.27×10^9	51.15×10^9	64.03×10^9

Table-4. Fertilizer energy input in Iran agriculture.

Year	**N** ($\times10^3$ton)	**Energy from N** (MJ)	**P_2O_5** ($\times10^3$ ton)	**Energy from P_2O_5** (MJ)	**K_2O** ($\times10^3$ ton)	**Energy from K_2O** (MJ)	**Total energy input** (MJ)
1980	408	26275.20×10^6	290	3468.40×10^6	12	91.2×10^6	29.83×10^9
1985	475	30590.00×10^6	437	5226.52×10^6	12	91.2×10^6	35.91×10^9
1990	567	36514.80×10^6	590	7056.40×10^6	24	182.4×10^6	43.75×10^9
1995	632	40700.80×10^6	367	4389.32×10^6	12	91.2×10^6	45.18×10^9
2000	830	53452.00×10^6	395	4724.20×10^6	107	813.2×10^6	58.99×10^9
2005	883	56865.20×10^6	399	4772.04×10^6	90	684.0×10^6	62.32×10^9

Table-5. Pesticide energy input in Iran agriculture.

Year	**Pesticide** (1000 ton)	**Energy Eqv.** (MJ)
1980	9266	0.93×10^{9}
1985	23136	2.32×10^{9}
1990	53964	5.40×10^{9}
1995	13661	1.37×10^{9}
2000	22555	2.26×10^{9}
2005	55560	5.60×10^{9}

Table-6. Seed energy input in Iran agriculture.

Year		**Cereals**	**Pulse**	**Oilseeds**	**Potato**	**Sugar beat**	**Cotton seed**
1980	Area sowing (ha)	8488132	381904	110785	115249	168423	145000
	Seed rate (kg)	967647048	27115184	3877475	259310250	673692	3625000
	Energy eqv. (MJ)	1.42×10^{10}	3.99×10^{8}	9.69×10^{7}	9.34×10^{8}	3.40×10^{6}	9.1×10^{7}
	Yield	2302.9	977.24	1535.9	12828.44	21662.7	1279
1985	Area sowing (ha)	8802087	471138	104613	144469	176588	187936
	Seed rate (kg)	1003437918	33450798	3661455	325055250	706352	4698400
	Energy eqv. MJ)	1.48×10^{10}	4.92×10^{8}	9.15×10^{7}	11.70×10^{8}	3.56×10^{6}	11.75×10^{7}
	Yield	2608.3	927.6	1265.7	11729.2	28117	1689.4
1990	Area sowing (ha)	9482074	534097	192857	148697	148576	221094
	Seed rate (kg)	1080956436	37920887	6749995	334568250	594304	5527350
	Energy eqv. (MJ)	1.59×10^{1}	5.57×10^{8}	16.87×10^{7}	12.04×10^{8}	3.00×10^{6}	13.82×10^{7}
	Yield	1392.9	903.21	900.9	13194.64	24508.84	1600.5
1995	Area sowing (ha)	9062814	1109760	197854	144670	202693	272177
	Seed rate (kg)	1033160796	78792960	6924890	325507500	810772	6804425
	Energy eqv. (MJ)	1.52×10^{10}	11.58×10^{8}	17.31×10^{7}	11.72×10^{8}	4.09×10^{6}	17.01×10^{7}
	Yield	2577.75	1020.3	1422.11	12948.4	27239.7	1685.6
2000	Area sowing (ha)	8179996	1144699	324023.8	174561.6	171658	250118.5
	Seed rate(kg)	932519544	81273629	11340833	392763600	686632	6252962.5
	Energy eqv.(MJ)	1.37×10^{10}	11.95×10^{8}	28.35×10^{7}	14.14×10^{8}	3.46×10^{6}	15.63×10^{7}
	Yield	3150.12	886.03	1731	14887.2	27083	1624.9
2005	Area sowing (ha)	9514272	907912.9	315735.9	189644.8	152875	159524.2
	Seed rate (kg)	1084627008	64461815.9	11050757	426700800	611500	3988105
	Energy eqv. (MJ)	1.59×10^{10}	9.48×10^{8}	27.63×10^{7}	15.36×10^{8}	3.08×10^{6}	9.97×10^{7}
	Yield	3317.8	1096.44	1752.1	15737.3	32067.94	1809.3

Table-7. Production values of major crops and their energy equivalents.

Crops		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**
Cereal	Product (kg)	19.55×10^{9}	22.96×10^{9}	13.21×10^{9}	23.36×10^{9}	25.77×10^{9}	31.57×10^{9}
	En. eqv. (MJ)	287.39×10^{9}	337.51×10^{9}	194.19×10^{9}	343.39×10^{9}	378.82×10^{9}	464.01×10^{9}
Pulse	Product (kg)	0.37×10^{9}	0.44×10^{9}	0.48×10^{9}	1.13×10^{9}	1.01×10^{9}	1.00×10^{9}
	En. Eqv. (MJ)	5.44×10^{9}	6.47×10^{9}	7.06×10^{9}	16.61×10^{9}	14.85×10^{9}	14.70×10^{9}
Oilseed	Product (kg)	0.17×10^{9}	0.13×10^{9}	0.17×10^{9}	0.28×10^{9}	0.56×10^{9}	0.55×10^{9}
	En. Eqv. (MJ)	4.25×10^{9}	3.25×10^{9}	4.25×10^{8}	7.00×10^{9}	14.00×10^{9}	13.75×10^{9}
Sugar beet	Product (kg)	3.65×10^{9}	4.97×10^{9}	3.64×10^{9}	5.52×10^{9}	4.65×10^{9}	4.90×10^{9}
	En. Eqv. (MJ)	18.40×10^{9}	25.02×10^{9}	18.35×10^{9}	27.82×10^{9}	23.43×10^{9}	24.70×10^{9}
Potato	Product (kg)	1.48×10^{9}	1.69×10^{9}	1.96×10^{9}	1.87×10^{9}	2.60×10^{9}	2.98×10^{9}
	En. Eqv. (MJ)	5.33×10^{9}	6.08×10^{9}	7.06×10^{9}	6.73×10^{9}	9.36×10^{9}	10.74×10^{9}
Cotton seed	Product (kg)	0.19×10^{9}	0.32×10^{9}	0.35×10^{9}	0.46×10^{9}	0.41×10^{9}	0.29×10^{9}
	En. Eqv. (MJ)	4.75×10^{9}	8.00×10^{9}	8.75×10^{9}	11.50×10^{9}	10.25×10^{9}	7.25×10^{9}

Table-8. Energy input and output values in Iran agriculture (per hectare).

Input energy	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**
Physical power	9.25×10^9	16.55×10^9	22.52×10^9	29.88×10^9	44.78×10^9	64.03×10^9
Fertilizer	29.82×10^9	35.91×10^9	43.75×10^9	45.18×10^9	58.99×10^9	62.32×10^9
Seed rate	15.72×10^9	16.67×10^9	17.97×10^9	17.87×10^9	16.75×10^9	18.76×10^9
Pesticide	0.93×10^9	2.32×10^9	5.40×10^9	1.37×10^9	2.26×10^9	5.60×10^9
Total input energy	55.64×10^9	71.37×10^9	89.63×10^9	94.30×10^9	122.78×10^9	150.71×10^9
Total output energy	325.56×10^9	386.33×10^9	239.66×10^9	413.05×10^9	450.71×10^9	535.15×10^9
Output/input ratio	5.85	5.41	2.67	4.38	3.67	3.55