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Relationship between inputs and outputs of agricultural production converted into energy equivalents

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Over the last fifty years, the increasing farm size and the evolution of production methods have led to an increase in energy use, either direct or indirect (grey energy used to produce or transport inputs). This energy, essentially finite fossil fuel, has become more and more expensive and emits greenhouse gases. The research consisted of studying the links between energy consumption and economic results. The aim was to try to answer the following questions: will the necessary reduction in energy consumption, associated with less intensive agriculture, be accompanied by a fall in agricultural incomes? How can farmer's income be maintained and even improved whilst adopting low input methods?

The study involved data collection using questionnaires carried out on approximately sixty arable farms in Haute-Normandy (west of Paris, France). On each farm, energy balance is realised thanks to the energy equivalents of the inputs and outputs (Risoud, 1999).

Analysis of the results, using the measure of efficiency defined as the output / input ratio allows for the establishment of relationships between economic and energy variables (Lynam, Hardt, 1989). The results show a large dispersion of efficiency values among the farms, explained by the diversity of crops and the strategic choice of farmers to spare inputs.

Key words: energy efficiency, arable land, sustainable agriculture, economic results

INTRODUCTION

Since the beginning of the sixties, French agricultural productivity has increased, mainly as a result of using more and more inputs: fuel, fertilizers, pesticides, equipment, livestock feed sustained by the Common Agricultural Policy (CAP).

This intensification of agricultural practices has led to an excessive harm to the environment:

• the removal of hedges favoured streaming and erosion during heavy rains, resulting in damage to property or people, involving high costs for society and reducing the biodiversity;

• the high use of fertilizers and pesticides has reduced the quality of water in many places, making it unfit for human consumption in some cases and incurring costs to society.

The intensification of agriculture has also had an impact on the emissions of greenhouse gases (GHG) Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) estimates that French agriculture is responsible for 19% of GHG emissions (in France). These GHG emissions cause warming and climatic change.

International agreements (KYOTO, 1997) aim to regulate GHG emissions. Agriculture must therefore reduce its GHG emissions as well.

Simultaneously, the economic context of French agriculture is rapidly changing:

• increasing suppression of the market regulation tools with diminution of the protection at the borders;

• the rising cost of energy, caused by an increase in demand and the depletion of fossil fuels used by farmers (Pimentel et al., 1973).

These two factors, occurring together, can impact the income of the farmers who use the highest inputs.

Farmers need also to adapt to reducing GHGs and thus energy use. It is time to shift to the systems that use inputs more sparingly (Ministère de l'agriculture et de la pêche of France, 2008 and 2009).

This paper presents the methodology used and the ways how economic and energy efficiency has been defined in this text. Then, a wide range of energy efficiency and economic results of the farms that were studied will be shown. Finally, we shall present the dispersion factors and attempt to order them with the aim of proposing a system of production which reduces energy consumption whilst maintaining or improving farmers' income.

METHODOLOGY

1. Analysis of energy use in farms is a difficult methodological subject regarding:

- the energy equivalent of each category of input, especially the quantity of energy used to produce them;
- the quantity of energy used to distribute the input to the farms.

There are numerous methods of evaluation. Here PLANETE® is used. This tool was created at the end of the nineties by SOLAGRO, ADEME, ENESAD, CEIPAL and CEDAPAS. It has been widely tested (Bochu, 2007); (Ministère de l'agriculture et de la pêche, 2008); (Risoud, 1999) and is the most widely used method in France so that it has been well validated. It assists in the quantification of the incoming and outgoing energy flows of a farm. PLANETE® is a method based on the life cycle analysis (LCA) of a product (Ghertner, Fripp, 2007; Risoud, 1999). Thanks to a very complete table of equivalents, it takes into account all the inputs necessary for its production, analyses their environmental impacts on the soil, water and air and converts the energy used for the production either in mega joules (MJ) or in litres of oil equivalent. Once the quantity of each input is established, for example, a ton of fertilizer with a value of X MJ, PLANETE® can give its energy value.

2. The economic analysis is based on the gross operating surplus (GOS) defined as the added value to which deficiency payments are added and the labour costs are taken off. The gross operating surplus measures the economic efficiency of a farm disregarding the financial or investment policy of the farmer. It is used to pay the farmer's work, the capital invested on the farm and the auto financing of investments. But in fact, as we want to measure the real economic efficiency of the farms we shall use the gross operating surplus without aids (noted: GOSwa).

3. The sample consists of 58 randomly chosen arable farms on which 70% or more of the gross income is derived from crops. Most of farms in the sample have no livestock.

Data were chosen according to their accessibility and pertinence to the information they give and their complementarities with other data. The cropping year studied is that of 2006 because at the time of the inquiries some farmers had not yet got their accounts for 2007. The first part of the inquiry involved interviews with the individual farmers to gather technical information necessary to complete PLANETE® or explain the dispersion of results. During the second part, economic data were extracted from the farm accounts supplied by the farmers. The results from PLANETE were sent to the farmers with a short commentary.

4. Energy efficiency is defined as the ratio between the energy value of outputs and inputs. Lynam and Herdt's indicator: Output / Input (O / I) which is an indicator to decide whether an agricultural system is sustainable or not over one cycle of the system (a year) was used (Lynam, Hardt, 1989).

RESULTS

This study concerns the reduction of using energy from fossil fuel. That is the reason why energy efficiency, as defined above and referred to as O / I, is being presented and analysed at the level of the farm.

1. *The sample is composed of 58 farms.* Their average area is 183 ha. They employ 1.69 units of labour, i. e. an area of 108 ha per unit of labour. The surface of cereals, oilseed and protein plant average covers 89% and industrial crops 6% of the total area.

2. *The level of energy efficiency varies significantly from one farm to another* (Fig. 3). The most efficient farm reaches an efficiency level of 13.06, which means that for each joule used it produces 13.06 joules. Two farms are above the ratio

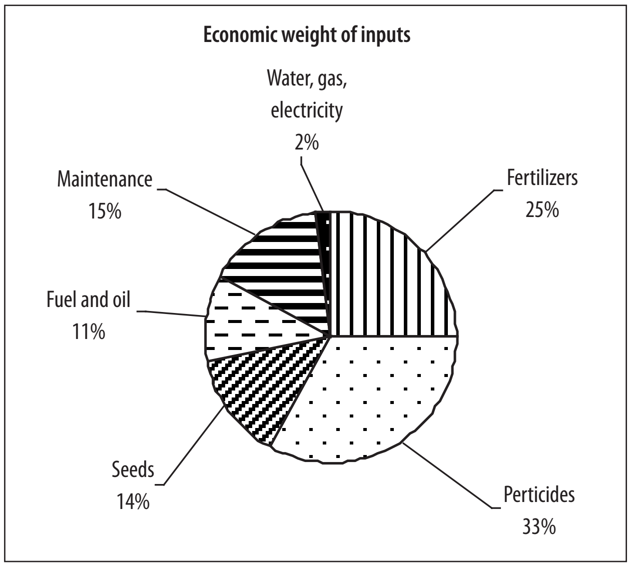

Fig. 1. Economic weight of inputs

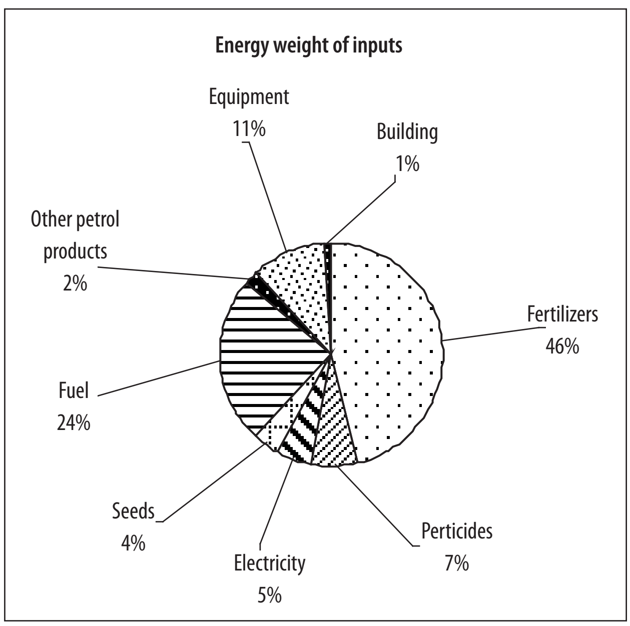

Fig. 2. Energy weight of inputs

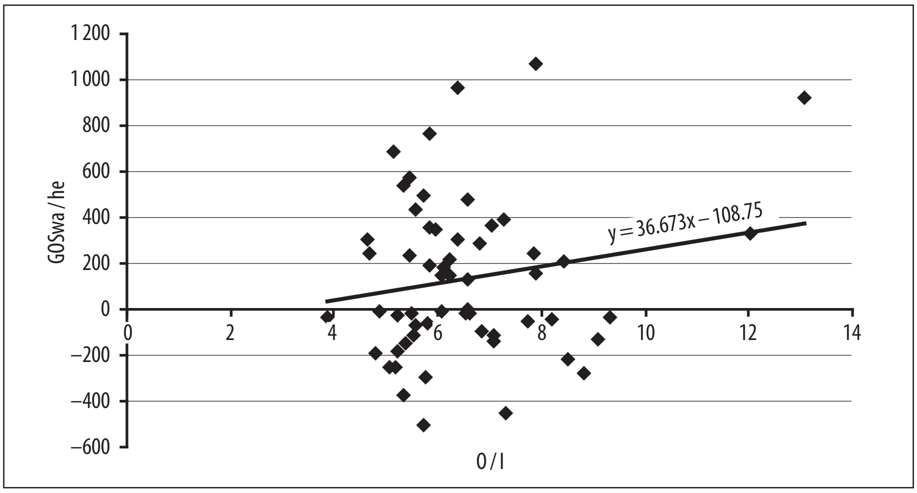

Fig. 3. Dispersion of the efficiency of farms

of 10. The average is 6.53 and the median 6.12. The least efficient farm has only a level of 3.87, which is 3.35 times less than the best one. The distribution in quartiles shows large gaps between the most efficient (average O / I = 8.7) and the least efficient (average O / I = 5.05) farms.

Higher efficiency can be attained by a high level of output, a low level of input or both of these two situations. The current trend consists of a preference for high levels of input for economic reasons (marginal product higher than marginal cost, creditworthy markets) or social ones (feeding the population). This study investigates the possibility of getting a high O / I with a low level of input. The analysis of the quartile, based on input, shows that the quartile using the highest level of energy input consumes 22.761 MJ / ha against only 12.926 MJ / ha for the lowest, however, they reach a level of output of 121.855 MJ / ha against 97.762 MJ / ha, respectively. The most productive quartile has an O / I of 7.56 and the least productive 5.35.

The analysis of the quartile based on output shows that the most productive farms attain 143.567 MJ / ha with an input of 19.736 MJ / ha, which gives an O / I level of 7.27. The least productive farms produce 84.425 MJ / ha using 14.471 MJ / ha and have an O / I level of 5.83.

The differences between quartile determined in the function of O / I are higher than those determined in the function of O or I. The reason is that in O / I the variations in I and the variations in O are cumulative.

Finally, one can see that the results of the study sample are higher than those found in other literature (Alam et al., 2005; Demircan et al., 2006, Erdal et al., 2007), but it should be noted that arable crop systems reach the highest energy efficiency and that the farms of this study are in a region where pedo-climatic conditions are very favourable and therefore not highly comparable. This dispersion of O / I agrees with the dispersion found by Bochu (Bochu, 2007) under different conditions.

3. *Relation between energy efficiency and economic results.* There is no direct relation between energy efficiency and economic results (Fig. 4). If the farm reaching the best O / I has a very good economic result (GOS wa/ha: 923 €/ha), the second best for O / I is situated in the middle of the group for its economic result. Almost 80% of farms have an O / I between 5 and 8, and their GOS wa/ha include the extremes of the sample. The farm that attains the best GOS wa/ha (1070 €/ha) gets an O / I of 7.88 and the worst (–503 €/ha) an O / I of 5.74.

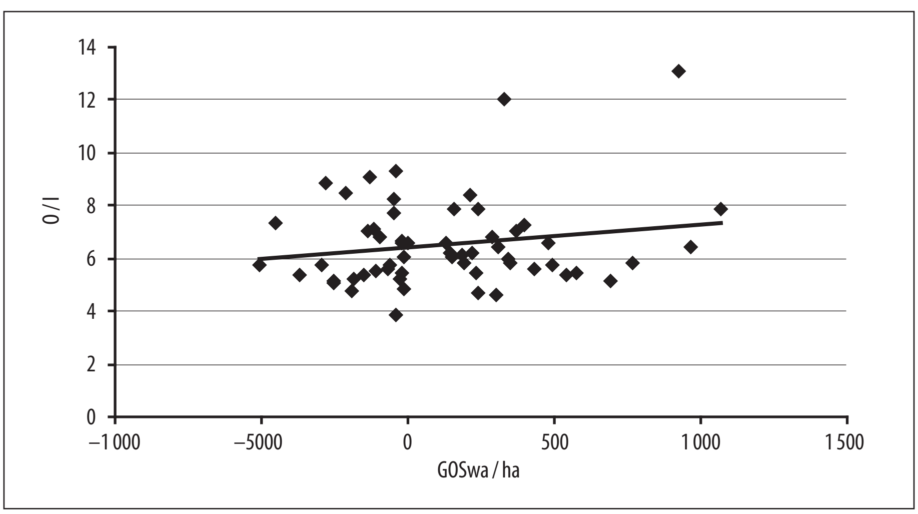

Fig. 4. Relation between energy efficiency and economic results

4. *Analysis of quartiles.* In this part, we try to find profiles of farms with an efficient energy use and getting the best economic results (Table). The distribution confirms the great disparity of the performances of the farms, because only three farms are in the best quartile (Q1) for O / I and GOS wa/ha (Nos. 29, 33 and 43). Do the most sparing farms have a better GOS wa/ha than the other ones? Only four farms situated in Q1 for I are also in Q1 for GOS wa/ha (Nos. 29, 33, 43 and 46). The most productive farms are also four in the Q1 for GOS wa/ha: Nos. 6, 25, 33 and 56. A single farm (No. 33) belongs to all the Q1. Its characteristics can be seen below. Only seven farms included in the QI for GOS wa/ha are also included in one Q1 based on the energy criterion.

5. *Detailed analysis of the first and the last quartiles of O / I* (Fig. 5). Are there significant different variables between Q1 and Q4 of O / I? The most efficient farms use less nitrogen per ha and in the rotation, less energy and less nitrogen for one product unit. They use less energy per hectare but produce more of it. Their efficiency is obtained thanks to their productivity and their frugality for energy. They also produce more net energy output per hectare (output–input). It is important because, thanks to photosynthesis, agriculture is the only economic sector able to achieve a positive energy balance.

6. *Correlations.* An analysis of correlations shows that the variables are not particularly correlated and only at low levels. If we consider that the coefficient of correlation 0.25 is significant, O / I is only correlated:

- to the area of industrial crop because those crops produce high outputs per hectare (beetroots, potatoes);
- to the length of rotation (0.25) that seems to confirm the necessity of diversifying crops;
- to the yield of wheat (0.37) and COP (0.27);
- to the quantity of energy produced per hectare (O) (0.57) confirming the correlation with yield and with the industrial crops;
- and negatively (–0.51) to the energy inputs, which could mean that efficiency depends more on reducing inputs than on high yields.

7. *A study of three remarkable farms.* We have demonstrated the dispersion of the different results and a weak correlation between the factors and the results. One of the aims

Table. **First quartiles**

N°	AV/ha	N°	GOSwa/ha	N°	O	N°	O/I	N°	O-I	N°	I
43	1 292	43	1 070	36	171 906	33	13,1	36	157 615	51	10 520
42	1 090	42	969	1	164 706	36	12,0	1	147 019	33	10 573
33	964	33	923	12	152 228	1	9,3	12	134 995	50	10 808
56	940	45	767	56	150 134	16	9,1	49	129 993	27	11 696
14	920	25	691	49	148 019	12	8,8	16	129 992	29	12 317
45	792	26	577	16	146 082	27	8,5	33	127 536	58	12 339
25	788	14	542	6	143 556	9	8,4	56	125 615	30	12 682
4	711	40	493	9	139 319	49	8,2	9	122 774	22	12 828
55	710	28	478	20	138 116	30	7,9	6	120 442	24	12 864
8	683	20	431	33	138 109	43	7,9	47	115 323	13	13 080
26	680	39	394	47	135 830	3	7,8	3	113 702	36	14 291
28	667	46	368	55	135 092	35	7,7	20	113 309	46	14 492
31	634	7	352	25	135 087	11	7,3	25	108 917	23	14 978
6	622	54	344	3	130 309	39	7,3	35	108 363	43	15 123
40	616	36	332	54	125 017	23	7,1	55	106 184	18	15 304

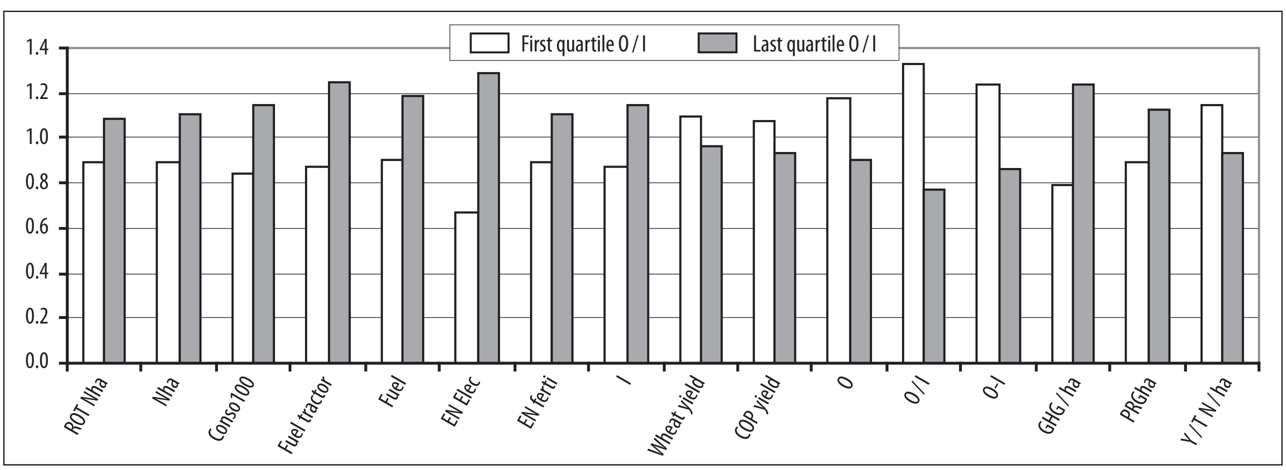

Fig. 5. Variables presenting significant differences between the first and the last quartiles

of this research is to provide farmers' counsellors with new knowledge. The study of the characteristics and practices of three remarkable farms may help us. We have chosen two most efficient (No. 33: O / I = 13.06 and No. 36: O / I = 12.03) and one least efficient farm (No. 10: S / E = 3.57).

We have found a few explanations for the gaps in the structural characteristics of these farms: silty soils; farms Nos. 10 and 36 employ more workers (1.2 UTH / 100 ha versus 0.7 for farm No. 33).

But industrial crops take up 11% of the area of farm No. 33 and 36% of the area of farm No. 36. Farm No. 10 doesn't produce industrial crops.

The farmers have different practices:

Farm No. 10 produces only two crops, thus having a lot of wheat on wheat (55%). The farmer sows 100% of wheat before the 10th of October (following the recommendations to get the best yields). He applies 28 units of N / T of wheat produced for a yield of 82 q/ha slightly inferior to the yields of the other farms. It is second to last for energy consumption.

Farm No. 36 is more intensive, probably because of the high percentage of industrial crops grown. Wheat sowing is displayed (because of the distribution of the work load in autumn), it spreads 21.5 UN / T of wheat produced for a yield of 87.7 q/ha. It is the eleventh for its energy consumption.

Farm No. 33 sows 50% of its wheat after the 20th of October, sprays only two fungicides and applies 15.5 UN / T for a yield of 84 q/ha. It cultivates five different crops, is the second most sparing for energy in the sample and has the third GOS wa/ha.

The determining points explaining the difference of performance seem to be the diversity of crops and the strategic choice of the farmer to spare inputs.

CONCLUSIONS

1. These results have to be confirmed. The study concerns the 2006 cropping year when COP prices were low. Would farmer No. 33 be so sparing if he knew that he could get a better price for his production?

2. We were unable to conclude using averages confirming what has been written on this subject. We thought that using a sample of farms from the same area with the same system of production we could get references allowing us to characterise the sparing system; however, the reality of the ground is more complex.

3. That's why the two next stages of this program are:

• to do the same study with milk farms but on two groups: the first one intensive and the second less intensive (using more grass and less inputs) to establish a reference;

• to survey arable farms known for being sparing, to compare them to our 2008 sample.

Then will come a period of estimated simulations to be able to make propositions to farmers and to their counselling organizations.

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References

1. Alam M. S., Alam M. R., Islam K. K. Energy flow in agriculture: Bangladesh. *American Journal of Environmental Sciences*. 2005. N 1. P. 213–20.
2. Azadeh A., Amalnick M. S., Gharderi S. F. et al. An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors. *Energy Policy*. 2007. N 35. P. 3792–3806.
3. Bochu J. L. Synthèse 2006 des bilans PLANETE : Rapport final. *ADEME-SOLAGRO*. 2007. N 3. P. 25.
4. Bochu J. L., Berger S., Priarollo J. Énergie dans les exploitations agricoles: état des lieux en Europe et éléments de réflexion pour la France – Synthèse. 2007.
5. Charnes A., Cooper W. W., Rhodes E. L. Measuring the efficiency of decision making units. *European Journal of Operational Research*. 1978. N 2. P. 429–444.
6. Demircan V., Ekinci K., Keener H. M. et al. Energy and economic analysis of sweet cherry production in Turkey: a case study from Isparta province. *Energy Conversion and Management*. 2006. N 47. P. 1761–1769.
7. Erdal G., Esengun K., Erdal H. et al. Energy use and economical analysis of sugar beet production in Tokat province of Turkey. *Energy*. 2007. N 32. P. 35–41.
8. Farrell M. J. The measurement of productive efficiency. *Journal of the Royal Statistical Society, Series A*. 1957. N 120. P. 253–281.
9. Ghertner D. A., Fripp M. Trading away damage: Quantifying environmental leakage through consumption-based: lifecycle analysis. *Ecological Economics*. 2007. N 63. P. 563–577.
10. Lynam J. F., Hardt R. W. Sense and sustainability : sustainability as a objective in international agricultural research. *Agricultural Economics*. 1989. N 3. P. 381–398.
11. Miettinen P., Hamalainen R. P. How to benefit from decision analysis in environmental life cycle assessment (LCA). *European Journal of Operational Research*. 1997. N 102. P. 279–294.
12. Ministère de l'agriculture et de la pêche. *Projet de loi de programme relatif à la mise en oeuvre du Grenelle de l'environnement*. 2008. Article 28.
13. Ministère de l'agriculture et de la pêche. *Circulaire DGPAAT/SDEA/C2009-3012*. 2009.
14. Pimentel D., Hurd L. E., Belloti A. C. et al. Food production and the energy crisis. *Science*. 1973. N 182. P. 102–443.
15. Risoud B. Développement durable et analyse énergétique d'exploitations agricoles. *Economie Rurale*. 1999. N 252. P. 16–26.
16. Uhlin H. Why energy productivity is increasing: an I–O analysis of Swedish agriculture. *Agricultural System*. 1998. N 56. P. 443–465.

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ŽEMĖS ŪKIO PRODUKCIJOS IŠTEKLIŲ IR PRODUKCIJOS RYŠYS, VERTINANT ENERGETINĮ ŪKININKAVIMO EFEKTYVUMĄ

Santrauka

Dėl per pastaruosius penkiasdešimt metų stambėjančių ūkių ir gamybos metodų evoliucijos padidėjo tiek tiesioginis, tiek netiesioginis energijos suvartojimas (pilkoji energija naudojama energijai gaminti ar perduoti). Tokia energija, iš esmės tai iš žemės gelmių išgaunamas kuras, tampa vis brangesnė ir išskiria šiltnamio dujas. Tyrimo metu buvo nagrinėjamas energijos suvartojimo ir ekonominių rezultatų ryšys. Tyrimo tikslas – pabandyti atsakyti į klausimus: Ar būtiną energijos suvartojimo mažinimą, susijusį su žemės ūkio intensyvumo mažinimu, lydės pajamų mažėjimas žemės ūkyje? Kaip galima išlaikyti ūkininkų pajamas ir jas net padidinti taikant mažo galingumo metodus?

Raktažodžiai: energijos efektyvumas, dirbamos žemės ūkiai, tvarus žemės ūkis, ekonominiai rezultatai