ENERGY ANALYSIS AND IRRIGATIONS ECONOMY

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Abstract
The authors propose in the present material an energy analysis of the irrigated agriculture in which the inputs as well as the outputs, respectively the production are evaluated in energy units, meaning in Kcal/ha. For inputs, different methods are being applied, depending on the nature of materials, products or of the energy forms, in this manner: a)the energy consumed as mechanical work of: human, animal or windmill, hydraulic, ecc. origin can be measured as such and expressed in any energy measurement unit; b)the energy released by different forms of fuel is measured also knowing the equivalence coefficients; c)the energy contained in engines, constructions, materials that either is consumed once (tying rope), either is consumed slowly during the time (the tractors and agricultural machines' wearing out). In turn, the main agricultural products and the entire plant taken as biomass are also energy carriers stored by means of photosynthesis.The authors operate an energy and economical analysis of the romanian agriculture based on the statistical data obtained during the last years of the planned economy (1986-1989). The analysis comprises two versions: a) the design numbers in which the energy production is evaluated based on some high yield per area (ha). As a consequence, the energy efficiency indicators, respectively the balance and the energy efficiency have higher values. b) Based on the real yields obtained during the respective period of time when the energy efficiency indicators are much lower and the economical efficiency indicators are at limit or even negative.Irrigated agriculture is a big energy consumer. Compared with the non irrigated technological system, the energy consumption is higher with 28-30% at cereals, with 48-50% at oil plants or with 53-55% at sugar beet. The commercial cost of the energy unit in the irrigated technological system depends on many factors, among which the most important are: the structure of cultures, the irrigation norms and the number of applications the degree of use of the effective irrigated area from an irrigation system; the pumping height and the water transport distance from the source to the irrigated area; the attainment of the estimated productivity parameters; the energy crisis are directly affecting the irrigation water crisis as well, as a resource as well as price, that is why, at national level, a judicious management policy of the irrigation water and its associated energy is reccomended.

Key words: *food, irrigation, water, energy.*

INTRODUCTION

Food, water, energy. Food's dependence on water, and of the water for the energy irrigations is a well known truism nowadays. In this field, the XXI century takes from the previous one a problem as global as it is controversial.

In the view of an uncontrolled demographic growth quartered in the poorest and hungriest area of EARTH, how will mankind's food be ensured?

The material is not intended to answer this question but to place the energy role and place in the production of a food surplus by irrigating the cultivated plants. Primary agriculture, the main food source in the energy consumption structure is increasing.

For a balance of the food sector of 16.5% from the total commercial energy consumption of the United States of America, John N. Walker and Wayne H. Smith [8] are proposing the following dissociation: production 2.9%; processing 4.8%; marketing 1.3%; food preparation inside the house 4.3%; foof preparation outside the house 2.8%; transport 0.4%.

Hence, the farmer's energy consumption represents less than 3% from the total and less than 1/5 (17.5%) from the energy consumed by the food system. Industrial processing, food preparation inside and outside the house are consuming at least the same, or more than the agricultural producer in order to obtain it.

Agriculture's balance in the energy consumption at the farm's level differ from region to region, as well as depending on the economical growth level. According to B.A.Stout [6], agriculture's balance in the energy consumption has been during the period of time 1972-1973 of 3.5% in the developed countries; 4.8% in the developing countries; 6.4% in the Middle East or of 3.2% in the countries with planned economy. For what concerns the balance of irrigations in the

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energy consumption at the farm's level, it would be of 14.1% from the total consumption after the mechanical works 44.6% and fertilization 33.7%.

In Romania, agriculture's balance in the energy consumption at national level has been of 1.9% in 1969, of 3.2% in 1989 and of 1.1% in 2009. But in absolute numbers, the agriculture has consumed 528 thousand tons of CF (conventional fuel) in 1969, 4307 thousand CF in 1989 (with almost 3 million ha exploited in irrigated systems) and 385 thousand t of CF in 2009 (with an irrigated area of 288 thousand of ha, 10 times smaller than the one irrigated in 1989).

In the present material the authors are proposing an energy analysis of the irrigations in which the inputs as well as the outputs, respectively the production, are evaluated in energy units, meaning Kcal/ha.

In Romania, the energy analysis has been the research topic especially for the Agricultural Economy Institute's researchers, since the early `80's of the past century [7, 3, 1, 4].

MATERIAL AND METHOD

At the basis of the present article is the work ,,*Irrigations in Romania's agriculture"* [Lup, 1997] whose V-th chapter deals with: The analysis of the irrigations energy, whose importance is growing with the intensification of the agricultural systems with the purpose of producing more food supplies. The analysis data are brought to date for the level of the year 2009.

A special analysis method is being used in which all technological consumptions, including the energy embedded in the infrastructure of irrigations and work equipments system, are expressed in energy units, respectively Kcal, KWhour, ecc.

On the other hand, the harvest, the main one – grains - as well as the secondary one is expressed in the same energy units. For the inputs, different methods are being applied, depending on the nature of materials, products and forms of energy, as it follows:

a) the energy consumed as mechanical work of: human, animal or windmill, hydraulic, ecc. origin can be measured as such and expressed in any energy measurement unit;

b) the energy released by different forms of fuel is measured also knowing the equivalence coefficients;

c) the energy contained in engines, constructions, materials that either is consumed once (tying rope), either is consumed slowly (the tractors and agricultural machines' wearing out).

A classification of the main forms of energy inputs in agriculture is presented in figure 1. In turn, the main agricultural products and the entire plant taken as biomass are also energy carriers stored by means of photosynthesis.

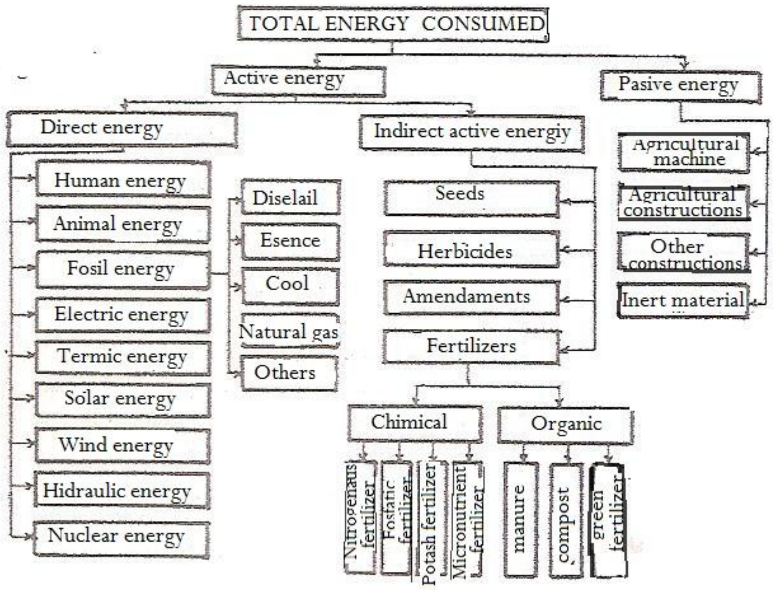

Figure 1. Schema structures the energy consumption in plant production (after I.Teşu and V.Baghinschi)

Thereat, an indication must be made: the plants' energy content is slightly different for different parts of the plant and even within some groups of plants, such that the main product is not usually much higher than the secondary one (stems, leaves ecc.). Nevertheless, we cannot consider as equal the two categories of products (at least for the actual stage of development of the secondary production).

Taking into account at „inputs" the main production, as well as the secondary one, leads to a significantly higher energy efficiency.

RESULTS AND DISCUSSIONS

Energy analysis of the agricultural technological processes.

The energy analysis represents an investigation method or, rather an original concept of approaching the technological processes that allows the results' comparison with the effort made to obtain them, expressed in a single measurement unit. Similarly, the value system, the energy unit (caloric units, joule). The analysis allows the measurement of any product, matter, energy resource consumed or produced in a simpler or more complex technological process, going to an economical branch or even to a complex of branches (the agrifood sector, for example).

The energy analysis, unlike the economical one, is in fact the shift from the notion of „*cost*" to the one of „*resource*". Until recently, the assessment of results in agriculture was made only by two main criteria:

a) *efficiency,* expressed by the medium production at the area unit, livestock ecc.

b) *profitability,* respectively the economical efficiency of the allocation of factors, lately more searched, but with possible negative effects on the production's develompent.

But none of the evaluation criteria of the obtained results was not taking into account the fact that a series of results, although convenient from an economical point of view (at least for a certain stage), are limited.

The energy analysis and balance represent a method and, respectively, an indicator by which the economical future is approached not only from an economical point of view, but also acording to the resources rarity and environment protection criteria.

At the most general, the energy analysis involves the drawing up of an energy calculation at the inputs, as well as at the outputs from a technological process, the relationship between them being the energy efficiency.

The energy efficiency. It was first defined as a report between the total energy outputs and intputs. This would mean that at outputs it should be taken into consideration the entire produced biomass, including the secondary plant: stems, roots, ecc., that are not being used.

At inputs, it should also be taken into consideration the free energy sources, for example the solar one. In this case, we would obtain what we can call the *ecological efficiency,* formulated as it follows:

$$R = \frac{\text{Production used by man+production not used by the human}}{\text{Energy consumption with value+free energy consumption (from the sun)}}$$

For what concerns the free energy sources for the technological processes of plants production, they are practically represented exclusively from the solar energy transformed by means of photosynthesis in biomass with energy value, but with an extremely low efficiency (under 1%). In the specialists circles, it is known the expression *energy octopus* (la pieuvre energetique), that expresses the extreme dissipation of the solar energy. Thus, from the solar energy that enters the atmosphere, approximately 30% is reflected by it before it reaches the ground.

Also in the atmosphere, approximately 30-45% of radiations are lost. The soil receives in turn 5-10% of these to reflect again approximately 30% of the trapped radiations. Thus, just an insignificant quantity, appreciated at less than 1% is used in the photosynthesis process.

In fact, what happens if we include the solar energy in the balance? Of the 30 percent that reach the ground, only approximately 1-3% are found in the organic products, less than 1% take part in the biomass forming, and from it only 55% is harvested by the human.

The maximum solar energy quantity recovered by the human would be:

0,01 (photosynthesis useful efficiency) x 0,55 (part harvested by the human) x 100 (days of active plants) x 90 cal/cm^2/day (received by the soil) x 10^8 cm^2 at hectare x 10^3 cal/year $\neq 10^6$ kcal/year

Thus, only 50 x 10^6 kcal/ha pass into the biomass, which would correspond to a grain efficiency of 125 q/ha (grains and straws).

Worldwide, on an area of l,45 x 10^9 ha, the agriculture produces 8,7 x 10^9 tons of dry substance/year biomass, that would correspond to a value of 3,5 x 10^{16} kcal. But the caloric value of the plants production is of only 10^{16} kcal, so only 1/3 of the produced biomass is harvested, which means a huge waste of plant calories [4].

For what concerns the produced energy, we observe that most of the plant mass that remains on the field or that is exploited, represents half or less of what is being produced. The energy efficiency is significantly growing, but by introducing the energy contained by the secondary production into the calculation.

For this reason, the specialists are searching for new methods of exploiting the secondary products, by the most different means: in the animals' food, as fertilizer, in fuel, raw material for the production of biogas, even in constructions, ecc.

For what concerns the energy inputs, at first view it seems normal to be taken into consideration only the inputs with value, meaning the ones that represent, in one form or the other, a financial effort, the remittance of the work force, the fuel, the machines' wearing out, the irrigation water, the seeds and other materials, ecc.

Also here, the man, the agricultural science could intervene in the improvement of the energy balance. It is known the fact that not all plants have the same exploitation coefficient of the solar energy or of other ecological resources (pedological, agro-physical and agro-chemical factors, relief ecc.).

Currently, the energy efficiency is calculated as a report between the main and secondary production evaluated in commercial energy units and the commercial consumptions evaluated in energy units, as it follows:

$$R = \frac{\text{Produced energy}}{\text{Energy consumptions with value (that costs)}}$$

Thus, this efficiency would be nothing else than the productive efficiency of the commercial energy used in agriculture. In this case, the energy efficiency could grow by obtaining a higher quantity of energy, with a lower additional energy, with the same energy quantity or even lower energy consumption.

For what concerns the economical concept (the second one) of the energy efficiency, this allows an evaluation of the report inputs-outputs as the energy carrier biomass use degree is increasing. Also, according to the biological agriculture principles, the scondary production that is not being used, as well as the organic debris of the roots, are not considered as loss, including from an economical point of view. In any case, the energy analysis represents an extremely complicated method, used for fundamental research studies, while the economical analysis of the inputs and energy production could represent a particularly useful practical instrument to optimize the production activities in any agricultural department.

Energy analysis and energy efficiency calculation involves the inputs and outputs' quantification and separate integration for every element taking part in the technological process. This means that we need a common measurement unit in which we can convert the consumptions, as well as the obtained productions.

The most used energy measurement units, in order of frequency, are: the kilocalorie - kcal, the kilowatt hour - kWh, the conventional fuel - kg CF; the horse-power - HP/h.

The conversion in energy units is rather difficult considering the diversity and nature of the products that need to be taken into consideration.

For the agricultural products (outputs), the evaluation can be made by two methods:

a) measurement of caloric content obtained by direct combustion;

b) measurement of energy content broken down by the biochemical processes, method that cannot be applied to some groups as textiles, tobacco and others.

Analysis of the irrigations energy.

As a production factor, irrigations are appreciated as being a high energy consumer, competing with the mechanization and chemification. But their balance in the energy consumption on the whole agriculture is more modest in comparison with the first two factors because of the scale differences. While the mechanization's energy consumptions affect the whole cultivated lands, and the chemification most of them, the irrigations generate additional energy consumptions only on improved and exploited in an irrigated system areas.

We mentioned earlier that agriculture occupies a modest place in the country's energy balance, and the trend is downward. If in the year 1977 the agriculture had 4,9% of the energy resources on the entire economy, this balance has decreased at 3,6% in 1993 and only 2,9% in the year 1994 or 1,1% in 2009. Nevertheless, on the irrigated lands, the energy consumption is much higher.

Energy consumption structure in irrigations.

Irrigation requires the consumption of two categories of energy resources, meaning:

- Passive energy, embedded in the structure of the hydrotechnical systems: ducts, pipelines, water intakes, pumping and repumping stations, distribution network, electrostations or aggregates of putting under pressure, works of art etc;
- active energy, necessary to pump and distribute the water to the plants: electric power, fossil fuel, human energy or of any other nature.

Passive energy embedded in the hydrotechnical systems and the watering equipment's vary in very large limits, depending on the type of establishment and the watering method, on the used materials, conditions specific to the area etc.

At its turn, the active energy depends on the system's irrigation norms, watering method, constructive performances synthetized by the general efficiency of the pumping aggregates, watering network and equipment but also of the energy agent's nature (electric current, different fossil fuels, etc.).

According to the data, the passive energy embedded in the establishments for irrigations has been evaluated in round figures at approximately 13000 kcal/ha, and the annual consumption representing the wearing out at approximately 600 Kcal/ha/year, energy that is being consumed whether or not the system is being exploited, since it represents the physical wearing out of the infrastructure and equipment's.

Of course, depending on the constructive characteristics, on the materials, placement, but also according to the used methodology, the evaluation of the energy embedded in the establishments for irrigations, differ from system to system, as well as from one author to another. For example, for the hydrotechnical systems from Romania, E.Cazacu and colab. [2] evaluate the energy included at approximately 3600 kcal/ha for the single-core establishments and 5400 kcal/ha in the case of the plots of 2000 ha.

In these calculations are included the electrostations of putting under pressure – SPP - (560-1200 kcal/ha), but not the watering equipment. Also for the hydro improvement establishments from our country, Ecaterina Mihăescu, V.Blidaru and Gh.Pricop have evaluated the passive energy included at approximately 9600 kcal/ha [5].

All these numbers represent the energy invested in the construction of the infrastructure or in the fabrication of the equipments from which the annual quota is generated depending on the lyfe-cycle of different components of the irrigation system.

At the passive energy is added the active energy necessary to pump the distribution and to actually irrigate the plants. Some passive and active energy consumptions specific to the hydrotechnical systems from Romania have been evaluated as it follows:

Passive energy:

- Irrigation network with electro pumps (pumping and repumping) life-cycle 30 years 319.1 kcal/year
- Stations of putting under pressure +rain wings (life-cycle 15 years) 270.9 kcal/year

Active energy:

- Raising at 1000 m^3 water by pumping at 1 m height 10.8 kcal/1000 m^3
- Achieving the pressure in stations of Putting under pressure SPP of 1000 m^3 water 812.7 kcal/1000 m^3

According to these medium energy consumptions for Romania's irrigation systems from the `80's, the energy consumption has been calculated on structure at the area unit for the main cultivated plants (tab.1).

Table 1 Energy consumption structure at some Plants cultivated in Romania in an irrigated technological system

Specification	**U/M**	**Wheat**	**Maize**	**Sun-flower**	**Sugar beet**
Total consumption	***mcal/ ha***	***7324***	***7796***	***4270***	***13733***
of which:					
- direct active energy	Mca/ha	1166	2875	1266	4350
	%	*15.9*	*36.9*	*29.6*	*31.7*
- indirect active energy	Mca/ha	5203	3790	2167	7910
	%	*71.0*	*48.6*	*50.7*	*57.6*
- passive energy	Mca/ha	955	1131	837	1473
	%	*13.1*	*14.5*	*19.7*	*10.7*

Source: Teşu I., Baghinschi V.: *Energy and agriculture* [7] , p.136.

Energy production. In order to calculate the energy efficiency of an agricultural product, we also need the energy production embedded in the harvest of grains and stems or only grains.

The harvest's energy content at the plants given as example is the following[3] [9]:

– Wheat:-grains……………. 3.836 kcal/kg
  - straws…………… 3.646 ,,
– Maize: - grains ……..….. 3.921 ,,
  - cobs …………..... 3.653 ,,
– Sunflower: - seeds ……… 3.921 ,,
  - stems ..…………… 3.452 ,,
– Sugar beet: - roots ………. 0,980 ,,
  - packages and leaves .. 0.570 ,,

[3] *Energy allo wances and Feeding system for Ruminants.* Technical bulletin nr.33 Department of Agriculture, Londra, 1978.

For the crops estimated at the beginning of the `80's, the cultures from the previous table (1), considering the secondary production (straws, cobs), the following energy efficiency indicators have been calculated (tab.2).

The data from table 2 demonstrate the energy efficiency of the main cultures during the estimation and construction period of the big hydro improvement systems from Romania.

Considering of course also the solar energy input not taken into account.

Table 2 Designed energy efficiency of some culture plants in the technological conditions of the `80's

Culture	Yield Kg/ha	Produced energy Mcal/ha	Consumed energy Mcal/ha	Energy balance Kcal/ha	Energy efficiency
Wheat	5800	35240	7324	27916	4.81
Maize	9000	62677	7796	54881	8.04
Sunflower	3000	16977	4270	12707	3.98
Sugar beet	60000	70200	13733	56467	5.11

Source: Teşu I., Baghinschi V.: *Energy and agriculture* [7] , p.132.

For the actual technologies, more intense, with crops at hectare significantly bigger and lower irrigation norms, the energy efficiency that expresses the number of energy units produced with a consumed energy unit could be much higher: 7-8 for wheat, 10-12 for maize, 4-5 for sunflower or 8-10 for sugar beet.

In reality, due to an inadequate technical exploitation and especially of the shortage of direct and indirect active energy (fuel, electric power, fertilizers, pesticide) all assorted with many organizational dysfunctions, much lower crops than the estimated ones have been obtained. These in turn have affected to a large extent the efficiency of the irrigations energy (tab.3).

Table 3 Energy efficiency in Romania's agriculture on the lands exploited in irrigated and non irrigated system depending on the medium efficiency per hectare obtained in the period 1986-1989

Culture	Harvest Kg/ha	Energy production Mcal/ha	Energy consumption Mcal/ha	Energy balance Kcal/ha (col.3-4)	Energy efficiency (col.3/col.4)
1	2	3	4	5	6
Wheat	3350	19890	7324	12566	2.71
Maize	3850	26796	7796	19000	3.44
Soya	1155	9125	6734	2391	1.35
Sunflower	1595	9026	4270	4756	2.16
Sugar beet	26465	22495	13733	8762	1.6
Plant production in irrigated system	x	13203	6310	6893	2.09
Plant production (not irrigated)	x	11692	5042	6650	2.32

Source: Lup A.: *Irrigations in Romania's agriculture* [4], p.199.

The difference between the levels of the energy efficiency indicators, presented in the previous table, calculated using the project data and the ones from the above table calculated using the real efficiency obtained during the respective period of time is very high and is practically exclusively due to the low productions on hectare.

We notice that the energy efficiency obtained on the exploited lands in an irrigated system – 2, 09 - is even lower than the one obtained on the non irrigated lands – 2, 32.

Fact explained by the totally inadequate technologies applied on the so called irrigated lands where the electric power allocation for irrigations was insufficient (fig.2).

We notice that during the plants' maximum water consumption period of time, it should have been allocated to the irrigations almost one third of the electric power production at national level, thing that the economy structure from that period of time could not afford considering the huge consumptions of the industrial giants that were given absolute priority.

The economical efficiency of the agricultural production of the last years of the socialist agriculture.

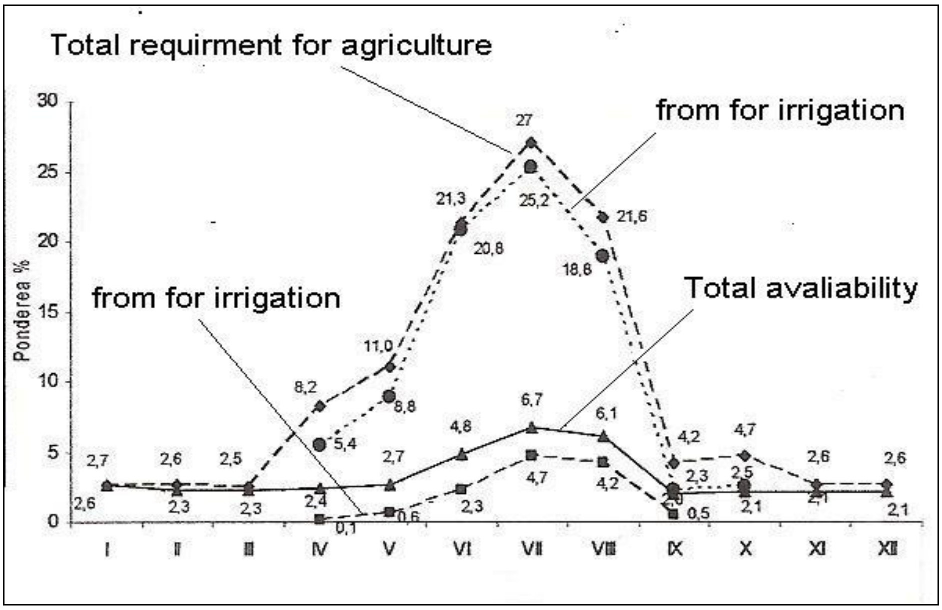

Figure 2. Season distribution of the large requirement and electric power consumption in agriculture and irrigations in relation to the consumption on the total of economy (1989)

The fall of the Romanian economy during the last years of socialism was largely due to the continuation in a fast pace of the investments without ensuring the resources necessary to their exploitation.

Table 4 Economical efficiency of some cultures depending of the yield per hectare (1986-1989) on the lands exploited in an irrigated system

Specification	U/M	Grain	Maize	Soya	Sun flower
Productions	kg/ha	3315	3850	1355	1595
Incomes	lei/ha	5967	5675	4472	4626
Technological costs	,,	5345	5583	5481	4382
Profit	,,	622	92	-1009	244
Profit rate	%	11.6	1.6	-18.4	5.6

Source: Calculations belonging to the authors.

At the end of the year 1989, over three million hectares were improved to be irrigated, but the target was of 5.5 million hectares, and the financial resources were more and more precarious.

The data from table 4 should not surprise. In 1989, for example, with almost one third of the arable area exploited in an irrigated system, the country's medium production was of 3364 kg/ha at wheat, 2472 kg/ha at maize, 593 kg/ha at soya, 1512 kg/ha at sunflower or 26465 kg/ha at sugar beet[4] [10].

For the irrigated aria the water was subsidized in proportion of over 75%, the water purveyor (the state) registering as loss the cost difference for the water pumping and distribution. On the other hand, the inadequate exploitation at the level of agricultural exploitations did not ensure any production increases that should cover the own expenses made with the irrigation of cultures. This state of affair is expressed synthetically in fig.3.

[4] Romania's statistical yearbook,1990.

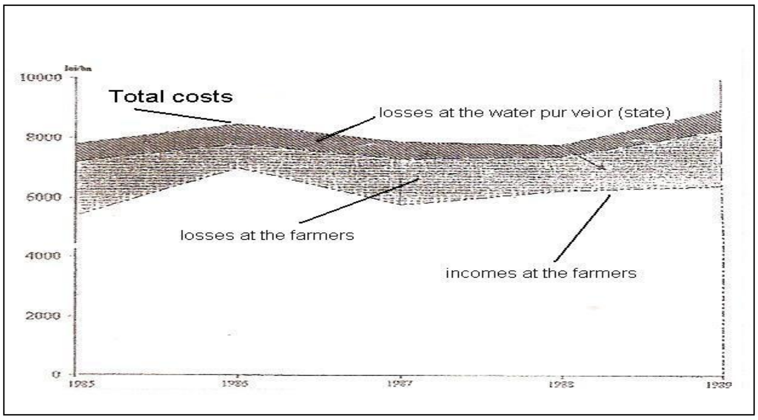

Figure 3. Economical efficiency of the plant production in an irrigated system at the level of agriculture (water supplier and user) in the case of state farms Constanta Trust during the period of time 1985-1989

CONCLUSIONS

1. The energy analysis is an original concept of research of the agricultural technological processes by which the obtained production, as well as any kind of comsumptions that contributed to its procurement are expressed in energy units: cal., kwh, joule.

2. Unlike the economical analysis in which the measurement unit is the one of value, the enegry analysis represents the shift from the category of „*cost*" to the one of „*resource*".

3. The agriculture, as branch of the national economy has a small balance in the energy complex structure, not exceeding 3-5% of the total, unlike the agro-industrial-food ensemble that could reach 18-20% from the total energy consumption in the developed countries.

4. Irrigated agriculture is instead a great energy consumer. Compared with the non irrigated technological system, the energy consumption is higher with 28-30% at cereals with 48-50% at oil plants or with 53-55% at sugar beet.

5. The commercial cost of the energy unit in the irrigated technological system depends on many factors, among which the most important are:

- The structure of cultures, the irrigation norms and the number of aplications;
- The degree of use of the effective irrigated area from an irrigation system;
- The pumping height and the water transport distance from the source to the irrigated area;
- The attainment of the designed productivity parameters,
- The energy crisis is also directly affecting the irrigation water crisis as, as a resource as well as price, that is why, at national level, a judicious management policy of the irrigation water and its associated energy is reccomended.

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