A METHOD FOR EVALUATION OF THE ENERGY POTENTIAL IN AN AGRICULTURAL FARM

V. Ros, Teodora Chira, G. Balc, L.Fechete

Abstract *A flexible and precise method for evaluation of the energy potential in agricultural farms is needed. In this paper attempt is made to develop an energy evaluation based on systemic analysis. The system consist of three major elements: the input energy W_I, the output energy W_O, and specific features S_f associated with the processes in the farm. A mathematical description of overall subdivisions of these elements is proposed. These description has the potential of achieving a quantitative analysis of energy balance in the farm, thus optimization of the energy consumption of all activities in the farm may be possible.*

Keywords: *agricultural farm, energy potential, energy input, energy output, energy balance.*

INTRODUCTION

The agriculture represents an important source of renewable energy. Agricultural farms have the possibility to become more efficient by using their energy sources which consist of their production (grain and plant production, animal products) and wastes. Some of the agricultural farms may become partially or totally independent of energy needed using in a proper way their energy sources.

Evaluation of energy potential in an agricultural farm requires a flexible program which may be adapted to the type and structure of the farm.

In the paper a method of evaluation of the energy input and output potential is developed. The method is based on systemic analysis, in which the agricultural processes are considered as a global system, with the generic title "FARM" and the specific activities (grain production, plant production, corn (maize) production, livestock etc.) are defined as subsystems. The systems is limited to a farm.

The method is flexible and can be extended and used for energy evaluation of all activities in a farm. The flexibility of the methods is given by its modular structure. Each module of the program represents the analysis of a subsystem. There may be added other modules for other application. This method may represents a useful tool for the farmers and permits to evaluate the energy balance of his farm, thus, to increase the efficiency of the farm.

1.DESCRIPTION OF THE METHODS

A better understanding of the efficiency of agricultural process is possible when the activities of the farm are quantify in terms of energy. This method allow to relate the outputs and inputs, by quantifying all the elements of the process.

Optimisation of the process requires a quantitative description of the interaction among the energy input (W_I), energy outputs (W_O) and other specific features of the process (S_f), by using a mathematical description of the process.

The evaluation of energy potential for a global system FARM is accomplished by analysing the energy balance, by estimation of input and output in the system (Fig.1).

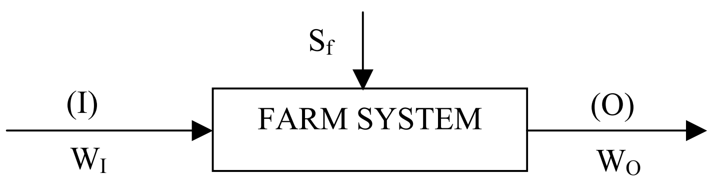

Fig.1 The general energy system named FARM.

The input (I) of the system consist of a function of energy input (W_I), or the total energy consumption associated to all activities (processes) in the farm. The output (O) of the system, represents the gross energy output (W_O), produced as a result of the processes and S_f – represent other specific features (characteristics) of the system which characterize the overall processes of the FARM system. It may includes: soil proprieties, technology applies in the farm processes, climate characteristics etc.

The total energy input W_I may be expressed as a sum of elemental (partial) energies associated to the elemental works required to develop the processes in the farm system, thus:

$$W_I = \sum_{i=1}^{n_1} W_{I.i}^{j}, \; i = 1, 2, 3, ..., n_1 \tag{1}$$

where: subscript I stand for input; i – the type of energy input; n_1 – the total number of different types of energy inputs in subdivision of order 1; superscript j stand for the order of the subdivision of the energy input.

Otherwise, the relation (1) may be expressed as:

$$W_I = W_{I.1}^1 + W_{I.2}^1 + W_{I.3}^1 + ... + W_{I.n_1}^1 \tag{2}$$

where: $W^1_{I.1}$; $W^1_{I.2}$, $W^1_{I.3}$; …; $W^1_{I.n1}$ represent the energies required for all activities associated to different type of inputs defined in the subdivision of order 1. Thus: $W^1_{I.1}$ - represents the energy input associated to farm machinery; $W^1_{I.2}$ - is the energy input associated to fertilizer (e.q. chemical fertilizer – production, transportation, distribution) and so on.

Each element of equation (2), presented in the subdivision of order 1, may be describe by a proper equation. For example, the energy sequestered in the farm machinery $W^1_{I.1}$ may be subdivided in different categories of order 2, thus;

$$W_O = \sum_{i=1}^{n_2} W_{I.1.i}^{2}, \; i = 1, 2, 3, ..., n_2 \tag{3}$$

where: n_2 represents the number of elemental energies in the subdivision of order 2 associated to farm machinery (production, repair, fuel).

Otherwise, the relation (3) may be written as:

$$W_{I1}^1 = W_{I.1.1}^2 + W_{I.1.2}^2 + W_{I.1.3}^2 + ... + W_{I.1.n_2}^2 \tag{4}$$

where the superscript 2 stand for the order o subdivision 2.

Partial development of the input system is carried through until each elemental energy may be expressed in a quantitative sense and can not be divided in lower subdivision.

In the same manner there may be analyse the term S_f (specific features of the system). The factor S_f is abstract because is not clearly defined quantitatively, but it represents distinct term in the energy system. Consequently, S_f may be called a functional element of the system and may be expressed by following functional relation:

$$S_f = f(S_C, C_C, T_C, …, O_C) \tag{5}$$

The factors in relation (5) are also, abstract but they do represent distinct elements in the energy system. S_C is associated to soil characteristics; C_C climate characteristics; T_C is associated to technology characteristics; O_C represents other characteristics.

According to the above concept, each element may be express in quantitative terms by using mathematical relation which allowed us to correlate the elements associated to these terms.

The overall energy output W_O, may be analysed in the same way as in the input analysis. The total output energy in a farm may be calculated by using the following relation:

$$W_O = \sum_{i=1}^{m} W_{Opr.} + \sum_{i=1}^{m} W_{Obpr.} \qquad (6)$$

where: $\sum_{i=1}^{m} W_{Opr.}$ represents the total energy embodied in the main products and $\sum_{i=1}^{m} W_{Obpr.}$ is the energy embodied in by-products. There are two way of evaluation of energy output.

The first method calculates the energy value of the primary products and by-products. The second method calculate the energy value of the secondary products (main secondary products and by-products) e.q. ethanol, vegetal oil etc. and then the analysis and energy balance will be done.

2. IMPLEMENTATION OF METHOD.

The method developed above may be implemented in a farm dealing with one main product, or in a mix farm production (grain crops, forage, animal production etc.)

For the implementation of the method let us consider a farm with maize (corn) production.

2.1. Definition and calculation of input variables for maize production.

For maize production the input $\mathbf{W_I}$ includes: $W^1_{I.1}$ – energy input associated to farm machinery; $W^1_{I.2}$ – energy input associated to fertilizer; $W^1_{I.3}$ – energy input associated to biocides; $W^1_{I.4}$ – energy input associated to crop propagation (corn); $W^1_{I.5}$ – energy input associated to irrigation; $W^1_{I.6}$ – energy input associated to transportation and storage; $W^1_{I.7}$ – energy input associated to manpower. In order to define and calculate the overall energy inputs we will design the energy flux for maize crop (Fig.2).

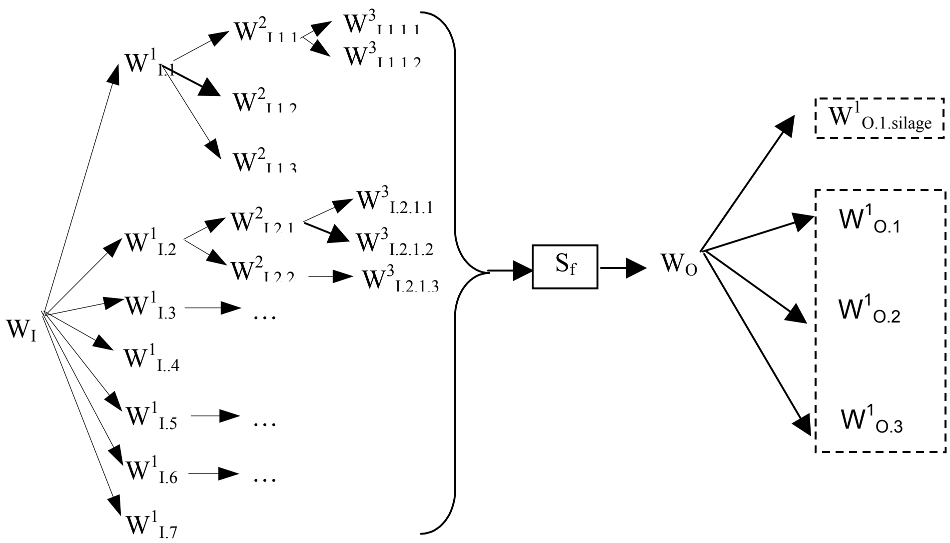

Fig.2. Energy flux for maize crop.

According to the flux diagram (Fig.2) and relation (2) the input energy for maize production is:

$$W_I = W^1_{I.1} + W^1_{I.2} + W^1_{I.3} + W^1_{I.4} + W^1_{I.5} + W^1_{I.6} + W^1_{I.7} \quad (7)$$

Each tem of relation (7) may be divided in other elemental terms (in the subdivision of order 2): $W^2_{I.1.1}$- energy associated to production of farm machinery; $W^2_{I.1.2}$- energy associated to repair of farm machinery; $W^2_{I.1.3}$- energy associated to fuels consumption. Thus:

$$W^1_{I.1}= W^2_{I.1.1}+ W^2_{I.1.2}+ W^2_{I.1.3} \quad (8)$$

Further $W^2_{I.1.1}$ can be subdivided in other two parts: $W^3_{I.1.1.1}$ – energy associated to material of farm machinery and $W^3_{I.1.1.2}$ – energy associated to manufacturing of farm machinery. Thus:

$$W^2_{I.1.1}= W^3_{I.1.1.1} + W^3_{I.1.1.2} \quad (9)$$

The terms in the relation (9) are considered the smallest term which may be expressed quantitatively as fallows:

$$W^2_{I.1.1}= [(A_{mat} + A_{manf})M_m]/T_f{\cdot}S \quad (10)$$

where: A_{mat} is the coefficient of energy consumption associated to farm machinery material, per mass unit [MJ/kg]; A_{manf} is the coefficient of energy consumption associated to farm machinery manufacturing, per mass unit [MJ/kg]; M_m – mass of farm machinery [kg]; T_f – lifetime of farm machinery; S – total cultivated area.

$W^2_{I.1.2}$ energy associated to repair of farm machinery:

$$W^2_{I.1.2} = B_{rep.m}{\cdot}\ M_m]/T_f{\cdot}S \quad (11)$$

where: $B_{rep.m}$ is the coefficient of energy consumption associated to farm machinery repair, per mass unit [MJ/kg] per year.

$$W^2_{I.1.3} = \sum_{i=1}^{k} H_{f.i} \cdot V_{f.i} \quad (12)$$

where: i the type of energy associated to activity; $H_{f.i}$ – calorific value of fuels consumed in activity i; $V_{f.i}$ - volume of fuels used per 1 ha, associated to activity i.

$\mathbf{W^1_{I.2}}$ include: $W^2_{I.2.1}$ – energy associated to *chemical fertilizer* and $W^2_{I.2.2}$ – energy associated to *organic fertilizer*, thus:

$$W^1_{I.2} = W^2_{I.2.1} + W^2_{I.2.2} \quad (13)$$

Further $W^2_{I.2.1}$ can be divided in tree parts of order 3: $W^3_{I.2.1.1}$ energy associated to production of chemical fertilizer; $W^3_{I.2.1.2}$ energy associated to package of chemical fertilizer; $W^3_{I.2.1.3}$ energy associated to distribution of chemical fertilizer:

$$W^2_{I.2.1} = W^3_{I.2.1.1} + W^3_{I.2.1.2} + W^3_{I.2.1.3} \quad (14)$$

$$W^2_{I.2.1} = (C_{prod,cf} + C_{pack,cf} + C_{trans,cf}){\cdot}M_{cf} \quad (15)$$

where: $C_{prod,cf}$, $C_{pack,cf}$, $C_{trans,cf}$ are the specific energy for production, packing and transportation consumption (MJ/kg), M_{cf} – mass of chemical fertilizer distributed per ha [kg/ha].

$W^2_{I.2.2}$ include the energy sequestrated in the organic fertilizer:

$$W^2_{I.2.2} = H_{bf} \cdot M_{bf} \tag{16}$$

where: H_{bf} - calorific value of organic fertilizer [MJ/kg]; M_{bf} – mass of organic fertilizer used per ha [kg/ha].

$\mathbf{W^1_{I.3}}$ include tree terms of order 2: $W^2_{I.3.1}$ - energy associated to biocide production; $W^2_{I.3.2}$ - energy associated to biocide package; $W^2_{I.3.3}$ - energy associated to biocide distribution:

$$W^1_{I.3} = W^2_{I.3.1} + W^2_{I.3.2} + W^2_{I.3.3} \tag{17}$$

$$W^1_{I.3} = (D_{prod,b} + D_{pack,b} + D_{trans,b}) \cdot M_b \tag{18}$$

where: $D_{prod,b}$, $D_{pack,b}$, $D_{trans,b}$ are the specific energy consumption for production, packing and transportation [MJ/kg]; M_b – mass of biocide used per ha [kg/ha].

$\mathbf{W^1_{I.4}}$ include energy sequestrated in seed:

$$W^1_{I.4} = H_s \cdot M_s \tag{19}$$

where: H_s - calorific value of seed [MJ/kg]; M_s – mass of seed used per ha [kg/ha].

$\mathbf{W^1_{I.5}}$ are divided in other two components: $W^2_{I.5.1}$ – energy associated to irrigation pump and $W^2_{I.5.2}$ – energy associated to production (manufacturing) of irrigation systems:

$$W^1_{I.5} = W^2_{I.5.1} + W^2_{I.5.2} \tag{20}$$

$$W^1_{I.5} = E_{ip} \cdot D_{ip} + E_{pi} \cdot M_{pi} \tag{21}$$

where: E_{ip} – energy consumption of irrigation pump [MJ/h]; D_{ip} – working time of irrigation pump [h]; E_{pi} – coefficient of energy consumption associated to manufacturing of irrigation system [MJ/kg]; M_{pi} – mass of irrigation system.

$\mathbf{W^1_{I.6}}$ include: $W^2_{I.6.1}$ – energy associated to transportation and $W^2_{I.6.2}$ – energy associated to storage of crop and wastes. Thus:

$$W^1_{I.6} = W^2_{I.6.1} + W^2_{I.6.2} \tag{22}$$

$$W^1_{I.6} = H_{fuels,Trans} \cdot V_{fuels,Trans} \cdot D_{Trans} + F_{storage} \cdot D_{storage} \tag{23}$$

where: $H_{fuels,Trans}$ calorific value of fuels used for transportation [MJ/L]; $V_{fuels,Trans}$ – volume of fuels used for transportation [L/h]; D_{Trans} – total time of transport [h]; $F_{storage}$ coefficient of energy consumption by storage per day [MJ/day]; $D_{storage}$ – time of storage [day].

$\mathbf{W^1_{I.7}}$ energy associated to labor can be calculate by different methods, in this paper is used the method based on the metabolic energy:

$$\mathbf{W^1_{I.7}} = G_{worker} \cdot H_{worked} \cdot N_{workers} \tag{24}$$

where: G_{worker} is coefficient of energy consumed by one worker per day [MJ/day]; H_{worked} – number of day worked; $N_{workers}$ – number of workers.

2.2. Definition and calculation of output variable for maize production.

The maize can be used like main product (seed, silage) or secondary products (ethanol, methanol, etc.).

In this case silage is considered as a main product:

$$W_O = H_{silage} \cdot M_{silage} \cdot S_{silage} \tag{25}$$

where: H_{silage} is calorific value of silage mass unit [MJ/kg]; M_{silage} – mass of silage resulted per ha [kg/ha]; S_{silage} – total area harvested.

In the second case, if the maize is used for production of secondary products, W_O can be divided in: $W^1_{O.1}$ – energy embodied in seed; $W^1_{O.2}$ – energy embodied in vegetal material (straw); $W^1_{O.3}$ energy embodied in agricultural waste:

$$W_O = W^1_{O.1} + W^1_{O.2} + W^1_{O.3} \tag{26}$$

In this order $W^1_{O.1}$ can be calculated by the relation (27) or (28):

$$W^1_{O.1} = H_c \cdot M_c;\ W^1_{O.2} = H_{VM} \cdot M_{VM};\ W^1_{O.3} = H_{Seed} \cdot M_{Seed} \tag{27}$$

where: H_c, H_{VM}, H_{Seed} are the calorific value of seed, vegetal material and wastes per mass unit [MJ/kg] and M_c, M_{VM}, M_{Seed} are the associated mass per hectare [kg/ha].

In the case of secondary products:

$$W^1_{O.1} = W^2_{O.1.1} - W^2_{O.1.2}$$

$$W^1_{O.1} = H_{sp} \cdot M_{sp} - I_{prod.sp} \cdot M_{sp} \tag{28}$$

where: $W^2_{O.1.1}$ – energy embodied in secondary products; $W^2_{O.1.2}$ – energy consumption to produced secondary products; H_{sp} – calorific value of mass unit or volume unit of secondary products [MJ/kg or MJ/L], M_{sp} mass or volume of secondary products resulted [kg or L]; $I_{prod.sp}$ coefficient of energy consumption associated to produced secondary products.

2.3. Definition of specific features of the process.

The main specific feature, of the process for maize crop is: total cultivated area; soil parameters: soil type, soil texture, soil structure, soil density, etc.; type of hybrid; vegetation factors; technology of cultivation: rotation, fertilization; tillage soil (technology for plowing, seeding, cultivation, fertilization, spraying, harvesting, transportation, storage etc.); environmental condition (the quantity of sunlight per m^2, precipitation etc.). All this parameters represent the features of the abstract term S_f.

Systemic analysis requires to express these parameters through mathematical relations in order to interrelate the main elements of the systems.

3. NUMERICAL APPLICATION

An energy balance analysis was developed for maize crop (the main product is the seed maize).

The characteristics used for the calculation of $W_I = f(W^1_{I.1}, W^1_{I.2}, ..., W^1_{I.6})$; $S_f = f(S_C, C_C, T_C, \ldots, O_C)$ and $W_O = f(W^1_{O.1}, W^1_{O.2})$ are listed in Table 1.

Table 1

Technology of maize production and the main characteristics

Operation	Operating equipment	Mass of equipment [kg]	A_{mat} + A_{manf} [MJ/kg]	A_{rep} [MJ/kg]	Diesel fuel consumption [L/ha]
Plowing	Tractor - U650	2500	138	10	30
	Plow - PPx30	990	180	6	
Seedbed preparation	Disk harrow - GDx3,4	1250	149	6	9x2
Seed planting	Seeder - SPC6	700	133	6	5,5
Fertilizer distribution	Centrifugal spreader	950	129	6	2
Cultivation	Cultivation equipment	3000	110	10	15
Herbicides spraying	Spraying Machine	800	128	6	3
Harvesting	Combine C12	4500	116	10	18

- Total area cultivated: 10 hectares [ha];
- Type of soil: cernoziom – no irrigation;
- Fuel: Diesel with H_c = 47,8 [MJ/kg];
- Chemical fertilizers:

Type of fertilizer	C_{prod} + C_{pack} + C_{trans} [MJ/kg]	Fertilizer mass per ha [kg/ha]
N	78,1	100
P_2O_5	17,4	50
K_2O	13,7	60

Obs: The energy input associated to fertilizer application was included in the energy associated to farm machines.

- Atrazin was used as herbicide (190 [MJ/kg]);
- Energy content of seed – 100 [MJ/kg];
- Seed mass – 20 [kg/ha];
- Seed production – 4500 [kg/ha] with 13 [MJ/kg] calorific energy;
- Vegetal material production – 5625 [kg/ha] with 14,7 [MJ/kg] calorific energy.

A software was developed to calculate and analyze the energy balance in the FARM. The results of energy analysis are given in figure 3.

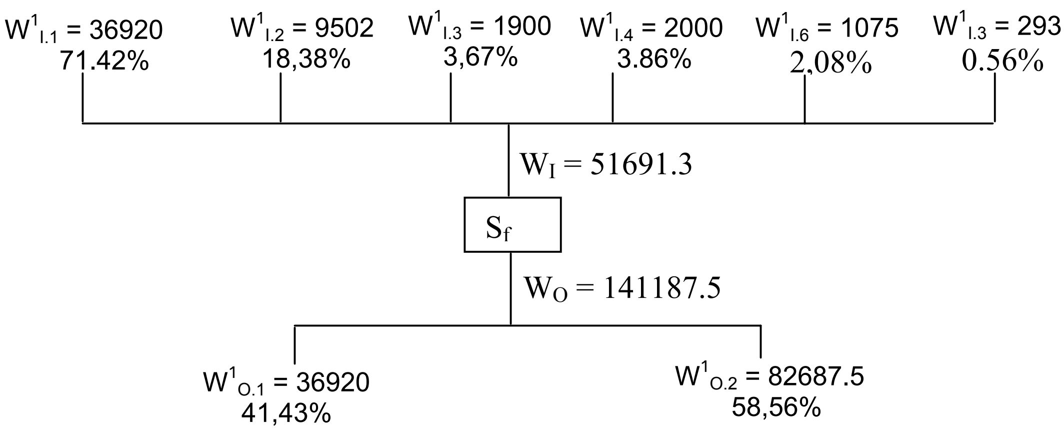

Fig.3. Energy balance of maize crop. W is expressed in [MJ].

Analyzing the results, it is obvious that the energy consumption associated to farm machinery has the highest percentage from the total energy consumption (71,42%). Optimizing the working process through energy consumption may be done through the improvement of technology or using other machines. Also it can be seen that 58,56% from output energy is embodied in vegetal products. In order to avoid energy loose the secondary products must be fully used through conversion in other energy forms (thermal energy, electrical energy etc.).

CONCLUSION

The method is flexible and can be extended and use for energy evaluation of all activities in a farm. The flexibility of the methods is given by its modular structure. Each module of the program represents the analysis of a subsystem.

This method allows to establish the magnitude of each type of partial energy embodied in the total energy input (W_I). Energy output (W_O), as well as, the magnitude of energy associated to each activity in the overall process (S_f), thus optimization of the energy consumption of all activities in the farm may be possible.

A computer program was developed and tested in the numerical application. Optimization of the process requires a quantitative description of the interaction among the energy input (W_I), energy outputs (W_O) and other specific features of the process (S_f), by using a mathematical description of the process.

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