THE ESTIMATION OF ENERGY EFFICIENCY OF CROP ROTATION IN LONG –TERM TRIALS

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Abstract
The aim of the work is to establish the energy-efficiency of long-term experimental field "Sidrabini" at the Research Institute of Agriculture of Latvia University of Agriculture. The crop rotation of winter triticale, spring wheat, spring barley, spring oilseed rape and potato was tested on the influence of increasing fertilizer rates during 1994 – 2008. Four fertilizer doses were tested: NPK 0-0-0, NPK 45-30-45, NPK 90-60-90 and NPK 135-90-135. Energy-efficiency was calculated using methodology developed by the Moscow Timirjazev Russian State Agrarian University (Методология и методика…, 2007).
Research results show that the spring rape used 32 GJ ha^{-1}, cereals consumed 30 -35 GJ ha^{-1} and potatoes - 66.5 GJ ha^{-1} of energy, but the yields were obtained: 42 GJ ha^{-1} from oilseed rape, 46–63 GJ ha^{-1} by cereals and 119 GJ ha^{-1} from potatoes. The energy efficiency ratio was 1.3 for spring rape, 1.5–1.8 for cereals and potatoes - 1.8.
The highest energy efficiency was obtained by growing triticale and potato, but lowest - growing spring oilseed rape. Growing a crop without a fertilizer, energy expenditure was equal to the energy accumulated in the yield (energy efficiency ratio 1.0), but using fertilizers, regardless of the fertilizer rate, the energy efficiency ratio was 1.6.
Key words: energy efficiency, mineral fertilizers, crop rotation.

Introduction

Every day mass media inform that fossil energy raw materials slowly become exhausted on Earth. Energy saving is urgent today in completely different way. Therefore, ever more attention must be drawn to renewable natural resources, which can be used for energy production.

A total amount of energy resources used for growing energetic cultivated plants (fuel, mineral fertilizers, etc.) often exceeds an amount of energy obtained from the product produced. Energy invested in production comes mostly from non-renewable natural resources, which, with their exhaustion, become more and more expensive. Energy utilization efficiency improvement is significant. Therefore, on 28 January 2010 Latvia adopted the law on energy end-consumption efficiency, which also concerns agriculture (Energy End-consumption Efficiency Law, 2010). A lot of attention in plant cultivation industry is currently paid to growing of energetic plants (*Renewable energy resources…*, 2008; Adamovičs et. al., 2009), however, energy utilization in plant cultivation technologies is not sufficiently valued and energy-efficiency thereof is not sufficiently analysed.

Growing conditions, especially use of mineral fertilizers, significantly affect chemical composition of products. Content of proteins and fats in those products changes, which alters energy content in yield. This must be taken into account in evaluation of cultivated plant growing technologies or varieties. Knowing the total amount of energy consumed for growing of cultivated plants and energy content in products enables evaluation of energy-efficiency of growing cultivated plants.

Energy-efficiency evaluation allows comparing different agricultural production technologies in respect of energy-resources consumption, establishing structure of energy flows in agrophytocenosis and identifying main reserve energy saving technologies in agriculture.

The aim of the research was to establish the energy-efficiency of long-term experimental field "Sidrabini" during 1994-2008.

Materials and Methods

In 1981, the agency of Latvia University of Agriculture, Research Institute of Agriculture, under the leadership of professor J. Štikāns arranged a long-term experimental field in gleyic sod-podzolic soil (PGg) with sandy loam granulometric composition. Main field crops – rye, triticale, spring barley, spring wheat, oats, potatoes, spring oilseed rape – as well as perennial grasses in I and II years of use were cultivated at long-term experimental field "Sidrabini". Four variants with different content levels of soil organic substances, soil reaction, plant nutrients – nitrogen, phosphorus and potassium created at the station. The test was arranged according to a two factors scheme, which allows for studying the effect of four lime doses (0; 2.85; 5.7 and 11.4 tons per hectare) on yields of cultivated plants; these variants

$N_0P_0K_0$	F_0L_0 0 t ha^{-1} $CaCO_3$	$N_{90}P_{60}K_{90}$	F_2L_0 0 t ha^{-1} $CaCO_3$
$N_0P_0K_0$	F_0L_3 11.4 t ha^{-1} $CaCO_3$	$N_{90}P_{60}K_{90}$	F_2L_1 2.85 ha^{-1} $CaCO_3$
$N_0P_0K_0$	F_0L_2 5.7 t ha^{-1} $CaCO_3$	$N_{90}P_{60}K_{90}$	F_2L_2 5.7 t ha^{-1} $CaCO_3$
$N_0P_0K_0$	F_0L_1 2.85 ha^{-1} $CaCO_3$	$N_{90}P_{60}K_{90}$	F_2L_3 11.4 t ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_0 0 t ha^{-1} $CaCO_3$	$N_{135}P_{90}K_{135}$	F_3L_0 0 t ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_3 11.4 t ha^{-1} $CaCO_3$	$N_{135}P_{90}K_{135}$	F_3L_1 2.85 ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_2 5.7 t ha^{-1} $CaCO_3$	$N_{135}P_{90}K_{135}$	F_3L_2 5.7 t ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_1 2.85 ha^{-1} $CaCO_3$	$N_{135}P_{90}K_{135}$	F_3L_3 11.4 t ha^{-1} $CaCO_3$

Figure 1. **The scheme of long-term experimental field "Sidrabini"**

were designated in the scheme as L_0; L_1; L_2 and L_3, and the effect of four norms of mineral fertilizers (NPK 0-0-0; NPK 45-30-45; NPK 90-60-90; NPK 135-90-135), designated respectively F_0; F_1; F_2 and F_3, on yields and quality of cultivated plants (Figure 1).

The study analyzes energy in respect of collected and consumed amount of energy of cultivated plants in the first rotation of plants for 7 years from 1994 to 2000 – and in the second rotation of plants for 7 years from 2002 to 2008. Calculations were based on the methodology of Russian State Agricultural University named after K. Timiryazev. Energy amount collected from the yield of cultivated plants was calculated using average factors of energy value equivalents (MJ per kg). Energy consumption for growing a specific variety of cultivated plants was determined by summing energy consumptions of individual technological operations according to the following formula:

$$E_c = \sum_{i=1}^{N}\left(Z_i^G \times K_i^G + Z_i^T \times K_i^T + Z_i^E \times K_i^E\right) + \left(t_i^D \times K_i^D + t_i^M \times K_i^M + m_i^D \times K_m\right) + E_p \tag{1}$$

where:

- E_c – total costs of energy for crop production (MJ ha^{-1});
- Z_i^G – fuel consumption (kg);
- Z_i^T – labour consumption (working hours);
- Z_i^E – power consumption (kWh);
- K_i^G – the energetic equivalent of fuel consumption (MJ kg^{-1});
- K_i^T – the energetic equivalent of labour consumption (MJ working h^{-1});
- K_i^E – the energetic equivalent of power consumption (MJ kWh^{-1});
- t_i^D – tractor-engine working hours (h);
- t_i^M – agricultural machinery working hours (h);
- K_i^D – depreciation of the energetic equivalent of one tractor-engine-time unit (MJ h^{-1});
- K_i^M – depreciation of the energetic equivalent of one agricultural machinery-time unit (MJ h^{-1});
- m_i^D – mass of material resources (kg ,m^3);
- K_m – mass equivalent of material resources (MJ kg^{-1}, MJ m^{-3});
- E_p – energy costs for equipment repair and servicing (MJ ha^{-1}).

Energy value ($E_{u)}$ collected from yield was determined according to the following formula:

$$E_u = U \times K_u \tag{2}$$

where:

- U – yield of crops (kg ha^{-1});
- K_u – energetic equivalent of yield (MJ kg^{-1}).

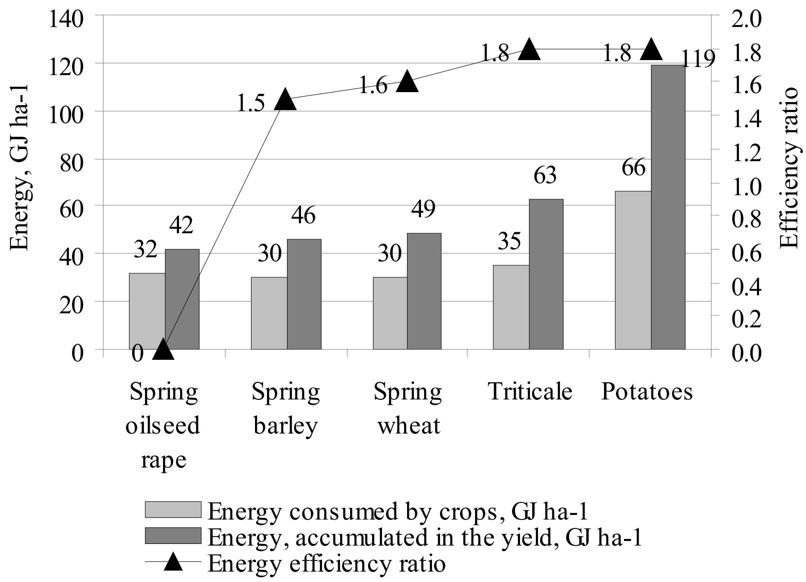

Figure 2. **Energy efficiency of crops**

Table 2

Energy efficiency of crops depending on mineral fertilizers norms

Crops	Norms of mineral fertilizers			
	NPK 0-0-0	NPK 45-30 45	NPK 90-60-90	NPK 135-90-135
Spring oilseed rape	0.9	1.7	1.8	1.6
Triticale	0.9	1.7	1.3	1.6
Spring wheat	1.3	1.8	1.6	1.6
Spring barley	1.3	1.7	1.8	1.5
Potatoes	0.7	1.2	1.5	1.7
Average	1.0	1.6	1.6	1.6

The factor of energy efficiency of agricultural cultivated plants, which was determined as a relation between energy capacity of obtained yield (energy collected with yield) and energy consumption for its obtaining (energy consumed for growing of cultivated plant), was used as a criterion of crop rotation energy efficiency:

$$K = \frac{E_u}{E_c} \quad (3)$$

where:

- K – energy efficiency
- E_u – energy accumulated in the yield (MJ ha^{-1});
- E_c – energy consumed by a crop (MJ ha^{-1}).

Results and Discussion

In making tests, first, energy consumed for obtaining the yield of field crops, grown in field tests, was established. Energy consumption was established by summing individual energy consumptions of technological operations and materials used in these field tests. Figure 2 summarizes results obtained in the tests regarding the study variant, where the norm of mineral fertilizers was NPK 90-60-90.

Energy efficiency ratio rating:

- K=0 – energy expenditure is equal to the energy accumulated in the yield;
- K>1 – the energy accumulated in the yield is higher than energy expenditure;
- K<1 – production consumes more energy than its generation

The least energy was consumed for obtaining of yield of grains of spring wheat and barley: 30 GJ per hectare, slightly more energy was necessary for obtaining of yield of spring rape and winter triticale: 32 GJ per hectare and 35 GJ per hectare, respectively. Approximately twice as much energy as for grain plants and for obtaining of yield of spring rape was consumed for obtaining of yield of potatoes: 66 GJ per hectare. However, growing potatoes, the highest amount of energy was obtained from the yield of nodules: 119 GJ per hectare. The next highest amount of energy was obtained growing winter triticale: 63 GJ per hectare. 49 GJ per hectare was obtained from spring wheat seeds, 46 GJ per hectare – from barley, and the least, just 42 GJ per hectare – from spring oilseed rapeseeds. Therefore, the highest energy efficiency factor was in yields of potatoes and triticale: 1.8, it was slightly lower for spring wheat and barley: 1.6 and 1.5, respectively, and the lowest – for spring rape: just 1.3. Field crop cultivation efficiencies, using different norms of mineral fertilizers, are shown in Table 2.

Test results show that the average energy efficiency factor without mineral fertilizers (NPK 0-0-0) was the lowest: 1.0. Using mineral fertilizers, spring rape and spring wheat had the highest energy efficiency factor in variant with the lowest norm of mineral fertilizers (NPK 45-30-45): 1.7 and 1.8, respectively, and the highest for winter triticale and potatoes it was, using the average norm of mineral fertilizers: 1.8, in its turn, for barley the highest energy efficiency factor was when using the highest norm of mineral fertilizers: 1.7. The average energy efficiency factor at the stage of crop rotation for all field crops grown in the tests with all three norms of mineral fertilizers was similar: 1.6. The study results show that the highest energy efficiency was obtained in growing winter triticale and potatoes, using the norm of mineral fertilizers NPK 90-60-90, and, growing spring wheat, the best energy efficiency factor was in variant with the lowest norm of mineral fertilizers NPK 45-30-45. Growing field crops without mineral fertilizers, yield was very low, and energy, used for growing, was equal to the energy value of obtained products.

Conclusions

The research results show that the spring rape used 32 GJ ha^{-1}, cereals consumed 30 -35 GJ ha^{-1} and potatoes - 66.5 GJ ha^{-1} of energy, but the yields were obtained: 42 GJ ha^{-1} from oilseed rape, 46–63 GJ ha^{-1} by cereals and 119 GJ ha^{-1} from potatoes. The energy efficiency ratio was 1.3 for spring rape, 1.5–1.8 for cereals and potatoes - 1.8.

The highest energy efficiency was obtained by growing triticale and potato, but lowest - growing spring oilseed rape.

Growing a crop without a fertilizer, energy expenditure was equal to the energy accumulated in the yield (energy efficiency ratio 1.0), but using fertilizers, regardless of the fertilizer rate, the energy efficiency ratio was 1.6.

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