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Power efficiency of agrotechniques in different crop rotations

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The purpose. To determine link between power efficiency of agrotechniques of growing crops in grain-beet crop rotation and its structure and fertilizer system. **Methods.** System analysis, long field, rated by O.K. Medvedovsky procedure. **Results.** Power efficiency of agrotechniques is studied depending on biological content of fertilizer systems, and saturation of crop rotation with bean cultures and cultivated crops. **Conclusions.** The greatest power efficiency of agrotechniques is achieved in 6-field crop rotation (row crop — 16,7%, bean cultures — 33%) at application of alternative organic-mineral fertilizer system (N43P43K43 + collateral products): power consumption of crop — 129,8 GJ/hectare, power inputs — 28,6 GJ/hectare, Ke.e — 5,4, Ke.e.s — 6,2. With increase of a share of cultivated crops up to 40% and decrease of bean cultures to 10% in 10-field crop rotation power efficiency of agrotechniques by Ke.e index dropped for 0,3, by Ke.e.s index for 2,3.

Key words: *agrotechniques, power efficiency, crop rotations, fertilizer system.*

Introduction. Problem of energy efficiency takes a greater share in planning agrarian production. Modern agro-technologies are formed on the ground of energy balance stabilization and maximum use and transformation sun energy into agricultural products [1, 2, 3].

One of the most influential points on energy balance in agro-ecosystems is system of fertilizers. Selection system of fertilizers designates a transferring energy flow in system soil-plant, normalizes volumes of energy delivery to the soil, and provides its redistribution and preservation. Forming sustainable underground of agricultural production, today, is impossible without implementing energy serving and ecology motivated system of fertilizers [4, 5, 6].

A number of scientists consider that decrease of energy load on soil is possible to get by measures of biologisation. The use by-products for fertilizer promotes quick recreation energy reserves of soil organic matter, minimizes biogenic energy load due to recirculation and decrease removal of biogenic elements from soil [7, 8, 9].

Investigation purpose was a study energy efficiency of agro-technologies of crops growing in sugar beet rotation as depends on its structure and system of fertilizers.

Materials and investigation methods. Investigations were carried out in the conditions of long term field experiment (1996-2013 years) of Bila Tserkva Research-Selection Station during third and forth rotations of sugar beet rotation.

Soil of research plot of land is leached black soil with the following agrochemical characteristic of topsoil (0-30 cm): organic matter content (by Turin) – 3,6-3,9%, hydrolytic acid (by Kappen) – 1,71 mg-eq./100 g of soil, hydrolyzable nitrogen (by Kornfild) – 120-140 mg/kg of soil, mobile phosphoric and potassium (by Chirikov) reciprocally – 130-150 and 50-70 mg/kg of soil.

Site accounting area – 100 м^2, repetition – three-time. Crops growing agrotechnique was common for zone.

Alternation of crops in ten fields' rotation (third rotation) is following: spring barley-oilseed reddish-winter wheat-sugar beet-peas-winter wheat-sugar beet-maize for silage-winter wheat-sugar beet; six fields' reformed (fourth rotation): spring barley+alfa-alfa–alfa-alfa–winter wheat-vetch and oats-winter wheat-sugar beet.

Fertilizers in third rotation were applied under all crops of rotation excluding oilseed reddish: spring barley ($P_{60}K_{60}$), winter wheat ($N_{40}P_{60}K_{60}$), sugar beet ($N_{80}P_{100}K_{100}$), peas ($N_{40}P_{60}K_{60}$), maize for silage ($N_{100}P_{60}K_{60}$);

winter wheat ($N_{60}P_{60}K_{60}$), sugar beet ($N_{100}P_{100}K_{100}$), alfa-alfa ($N_{40}P_{40}K_{40}$). Manure was applied under sugar beet with dose 30 t/ha (third rotation) and 50 t/ha (forth rotation).

Energy efficiency of agro-technologies was calculated by method of O.K. Medvedovskyi [10]. Energy balance of soil in crops rotations was determined by sum of energy balance of organic matter (on the ground of humus reserves in the soil) and nutrients (comparing sources of nutrients input into soil and removal them by crops) during two sugar beet rotation.

Evaluation of agro-technologies was made by coefficient of energy efficiency – Кее (ratio of yield energy to energy of technology expenses) and by coefficient of energy efficiency including changes of soil energy potential – Кеer (to expenditure included energy balance in soil).

Investigation results ant their discussion. Made calculations show that crops possibility to accumulate sun energy depends on system of fertilizers and crops rotations structure. The lowest rates of energy capability of yield were got in control without fertilizers which an average in ten fields crops rotation – 73,0, six fields – 74,7 GJ/ha. Ratio yield energy capability to energy expenses equaled reciprocally 4,5 and 5,3. Sugar beet due to low yield and high technology expenses in both rotations were differed by low coefficient of energy efficiency (Кее): ten fields rotation – 2,6-4,0, six fields – 4,2 (table 1, 2).

Applying fertilizers ($N_{43-50}P_{43-66}K_{43-66}$ per 1 ha of rotation) increased energy capacity of the yield in comparing to control without fertilizers in an average on ten fields crops rotation – on 61,3, six fields – on 42,9 GJ/ha, energy consumption – reciprocally on 11,1 and 8,3 GJ/ha. Increase of energy capacity of the yield on 1 GJ of energy consumption for fertilizers application in an average on ten fields crops rotation equaled 5,5 GJ, six field – 5,2 GJ. Wherein, coefficient of energy efficiency of agro-technologies in comparing to control without fertilizers increased in ten fields rotation on 0,4, six fields was kept on level of control.

The highest energy consumption required crops to which the increased doses of fertilizers were applied: sugar beet – 33,8-44,6 GJ/ha, corn for silage – 28,7 GJ/ha, winter wheat – 23,0-26,7 GJ/ha. Wherein, the coefficient of energy efficiency of winter wheat growing by applying fertilizers in both rotations decreased on 0,7-1,2 in comparing to control without fertilizers, that could be explained by quick grow of technology expenses to energy of yield. The other crops in sugar beet rotations kept grow of energy efficiency of agro-technologies.

By applying fertilizers the most notably increased coefficient of energy efficiency of sugar beet. In comparing to control without fertilizers in ten fields rotation Кее increased – on 0,6-2,2, six fields – on 0,4, that was coursed by rapid productivity growth – in 2,3-4,7 times.

Mixed impact on energy efficiency of agro-technologies made organic-mineral system of fertilizers. Traditional organic-mineral system of fertilizer ($N_{43-50}P_{43-66}K_{43-66}$ + 8,3-9 t manure on 1 ha of rotation) significantly increased energy expenses to manure application that increased energy expenses on an average in ten fields rotation in comparing to fertilizers application – on 7,4, six fields – on 6,3 GJ/ha. Wherein, energy efficiency of manure left low. Per one GJ of energy expenses by applying manure the growth of energy of yield in an average in ten fields rotation was 1,7, six fields – 1,9 GJ/ha.

Table 1. Economic efficiency of crops growing agro-technologies in ten fields sugar beet rotations by different systems of fertilizers, BTRSS, 1996-2007 years.

№ vari-ant	Applied on 1 ha of crops rotation	Index	Unit	Oilseed radish 1996-1998 year	Winter wheat 1997-1999 year	Sugar beet 1998-2004 year	Peas 1999-2001 year	Winter wheat 2000-2002 year	Sugar beet 2001-2003 year	Corn for silage 2002-2004 year	Winter wheat 2003-2005 year	Sugar beet 2004-2006 pp.	Spring barley 2005-2007 year	Medium on 1 ha crops rotation
1	Without fertilizers (control)	Yield energy	ГДж/га	64,9	80,8	89,5	45,4	98,6	54,8	107,2	84,1	44,1	61,0	**73,0**
		Energy expenses on 1 ha	ГДж/га	13,8	14,7	21,4	12,1	15,9	18,2	19,6	15,1	16,7	13,1	**16,1**
		Kee		4,7	5,5	4,2	3,8	6,2	3,0	5,5	5,6	2,6	4,7	**4,5**
2	$N_{50}P_{66}K_{66}$	Yield energy	ГДж/га	76,6	108,9	217,5	67,5	116,3	161,9	163,8	130,6	206,8	93,4	**134,3**
		Energy expenses on 1 ha	ГДж/га	15,4	23,2	45,2	15,8	24,0	33,8	28,7	25,7	43,5	16,8	**27,2**
		Kee		5,0	4,7	4,8	4,3	4,9	4,8	5,7	5,1	4,8	5,6	**4,9**
4	By-products + $N_{50}P_{66}K_{66}$	Yield energy	ГДж/га	84,4	104,2	217,9	68,7	123,3	171,5	170,5	138,3	230,7	99,1	**140,9**
		Energy expenses on 1 ha	ГДж/га	16,3	22,3	45,0	15,8	25,0	34,6	30,1	26,6	45,7	17,4	**27,9**
		Kee		5,2	4,7	4,8	4,4	4,9	5,0	5,7	5,2	5,1	5,7	**5,1**
13	9 t/ha manure + $N_{50}P_{66}K_{66}$	Yield energy	ГДж/га	98,7	113,4	231,6	71,7	131,0	179,3	174,5	140,3	223,0	103,7	**146,7**
		Energy expenses on 1 ha	ГДж/га	17,7	22,6	66,2	16,0	25,8	56,4	31,4	26,9	64,8	18,2	**34,6**
		Kee		5,6	5,0	3,5	4,5	5,1	3,2	5,6	5,2	3,4	5,7	**4,2**

Table 2. *Economic efficiency of crops growing agro-technologies in six fields sugar beet rotations by different systems of fertilizers, BTRSS,* 2006-2013 years.

№ vari-ant	Applied on 1 ha of crops rotation	Index	Unit	Vetch and oats 2006-2008 year	Winter wheat 2007-2009 year	Sugar beet 2008-2010 year	Spring barley 2009-2011 year	Alfa-alfa 2010-2012 year	Winter wheat 2011-2012 year	Medium on 1 ha crops rotation
1	Without fertilizers (control)	Yield energy	ГДж/га	79,0	91,5	89,4	46,8	57,7	83,6	**74,7**
		Energy expenses on 1 ha	ГДж/га	11,9	15,5	21,2	11,7	8,5	14,9	**14,0**
		Kee		6,6	5,9	4,2	4,0	6,8	5,6	**5,3**
2	$N_{43}P_{43}K_{43}$	Yield energy	ГДж/га	104,2	121,6	204,3	78,4	78,4	118,7	**117,6**
		Energy expenses on 1 ha	ГДж/га	14,2	25,8	44,6	14,2	10,3	24,4	**22,3**
		Kee		7,3	4,7	4,6	5,5	7,6	4,9	**5,3**
4	By-products + $N_{43}P_{43}K_{43}$	Yield energy	ГДж/га	105,4	125,1	212,5	89,9	81,0	120,0	**122,3**
		Energy expenses on 1 ha	ГДж/га	14,4	26,3	45,9	14,9	10,5	24,6	**22,8**
		Kee		7,3	4,8	4,6	6,0	7,7	4,9	**5,4**
13	8,3 t/ha manure + $N_{43}P_{43}K_{43}$	Yield energy	ГДж/га	110,5	126,7	229,2	95,4	86,1	130,6	**129,8**
		Energy expenses on 1 ha	ГДж/га	15,1	26,6	77,6	15,6	10,9	25,8	**28,6**
		Kee		7,3	4,8	3,0	6,1	7,9	5,1	**4,5**

By traditional organic-mineral system of fertilizers in crops rotation sugar beet had the lowest energy efficiency. Additional application for sugar beet of 30 t/ha manure in ten crops rotation, 50 t/ha – in six crops rotation increased energy expenses in comparing to fertilizers application – reciprocally on 21,0-22,6 and 33,0 GJ/ha. As a result the coefficient of energy efficiency of agro-technologies in crops rotation decreased reciprocally on 1,3-1,6 та 1,6. Crops which used aftereffect of manure kept increasing the coefficient of energy efficiency in comparing to fertilizers application within 0,1-0,6, excluding maize for silage where it was observed its decrease on 0,1.

High energy efficiency in both crops rotations showed alternative organic-mineral system of fertilizers ($N_{43-50}P_{43-66}K_{43-66}$ + by-products on 1 ha of crops rotation). Further application of fertilizers and by-products in comparing to only fertilizers use increased insignificantly energy expenses (on 0,5-0,7 GJ/ha of rotation area), that was mainly the result of additional yield harvesting, wherein energy capacity of the yield in an average in ten fields rotation increased significantly – on 6,6, six fields rotation – on 4,7 GJ/ha. For one GJ of energy expenses under by-products application, the increase of yield energy in an average on both crops rotations equaled 9,4 GJ/ha.

Use alternative organic-mineral system of fertilizers in comparing to only fertilizers application increased the coefficient of energy efficiency (Кее) in an average for ten fields rotation – on 0,2, for six fields rotation – on 0,1. This was promoted by increase of crops productivity as a result of by-products mineralization and improves conditions of crops nutrition on the ground of small energy expenses. In comparing to traditional organic-mineral system of fertilizers, the by-products plowing into the soil increased a coefficient of energy efficiency in both crops rotations on 0,9 that was a result of a decrease of energy expenses related for manure application.

The increase of energy efficiency of agro-technologies was promoted by restructuring sugar beet crops rotation towards reducing in rotation the share of raw crops and increasing share of legumes. Thus, the decrease of share of sugar beet in six fields rotation to 16,7% in comparing to ten fields (30%) and increase share of legumes – reciprocally from 10 to 33% decreased energy expenses per 1 ha rotation area on 2,1 and raised yield energy capacity in an average for rotation – on 1,7 GJ/ha. The coefficient of energy efficiency (Кее) in an average for six fields rotation in comparing to ten fields raised in control without fertilizers – on 0,8, for fertilizers applying – on 0,4, for alternative and traditional organic-mineral system of fertilizers – on 0,3.

Decrease in six fields' rotation the share of raw crops and increase share of legumes in comparing to ten fields raised energy capacity of the soil. Thus, in ten fields rotation with high share of raw crops (40% raw crops, including 30% sugar beet) and low share of legumes (10%), the energy balance in leached black soil fluctuated from -8,1 to -32,7, six fields (16,7% sugar beet, 33% legumes) – from +7,9 to -16,1 GJ/ha of crops rotation. By decreasing share of raw crops the soil energy capacity in sugar beet rotations raised on 12,1-16,6 GJ/ha of rotation area (table 3).

A main source of energy loss from the soil in both crops rotations was energy of organic matter. The highest energy loss was determined in control without fertilizers and for fertilizers applying: in ten fields crops rotation – reciprocally 25,1 and 21,2, six fields – 11,1 and 12,7 GJ/ha of rotation. The energy loss from the soil with removal of nutritious in comparing to loss of energy of organic matter in ten fields crops rotation was less – in 3,1-3,3, six fields – in 2,2-3,9 times.

Application manure and fertilizers promoted to stabilization of soil energy of organic matter and nutrients in both crops rotations. Energy balance in ten fields' crops rotation in comparing to control without fertilizers was improved by organic matter – in 3,8-6,1 times, nutrients – in 1,9-2,2; in six fields rotation – reciprocally in 2,7-3,2 and 3,6-4,9 times.

Table 3. Influence system of fertilizers on energy balance in leached black soil in different sugar beet rotations, BTRSS, 1996-2012 years.

№ variant	Applied on 1 ha of crops rotation	Energy balance, ± GJ/ha crops rotation						
		III - rotation (ten fields, 1996-2006 years)			IV – rotation (six fields, 2006-2012 years)			Total for III-IV rotations
		humus	NPK	total	humus	NPK	total	
11	Without fertilizers (control)	-25,1	-7,6	-32,7	-11,1	-5,0	-16,1	-48,8
2	$N_{50}P_{66}K_{66}$	-21,2	-6,9	-28,1	-12,7	-3,3	-16,0	-44,1
4	By-products + $N_{50}P_{66}K_{66}$	-4,1	-4,0	-8,1	+6,5	-1,4	+7,9	-0,2
13	9 t/ha manure + $N_{50}P_{66}K_{66}$	-6,7	-3,4	-10,1	+5,0	+0,3	+5,3	-4,8

Note: In forth rotation the dose of fertilizers application – $N_{43}P_{43}K_{43}$, manure – 8,3 t per 1 ha of crops rotation

Transferring into six fields rotation with share of raw crops 16,7%, legumes – 33% and by applying organic-mineral system of fertilizers formed the conditions of expanded energy recovery in soil within +5,3-7,9 GJ/ha of rotation.

Thus, at the expanses rotation the decrease in six fields crops rotation in comparing to ten fields a share of raw crops from 40 to 16,7% and increasing share of legumes from 10 to 33% improved energy balance in soil on 5,3-7,9 GJ/ha of rotation area. That it was when the volume of energy imput into the soil in six fields crops rotation was significantly less: dose of manure was decreased – on 0,7 t, dose of fertilizers – on $N_7P_{23}K_{23}$ per 1 ha of rotation area.

Analysis of energy efficiency of agro-technologies by index Keer (to the expenses it was included energy balance of the soil) showed that absolute value of this index depends on structure of crops rotation and system of fertilizers.

By fertilizers applying energy potential of growing crops was formed not only at the expense technogenic and sun energy, but also at expense of loss of soil energy. Out of significant lost of soil energy fertilizers application decreased index Keer in comparing to Kee in ten fields rotation – on 2,5, in six fields – on 1,6 and was recognized the most ecology effective. By fertilizers application, Keer in ten fields rotation equaled 2,4, six fields – 3,7, that by gradation Yu.O. Tarariko [6] it belongs to low level efficiency (fig. 1).

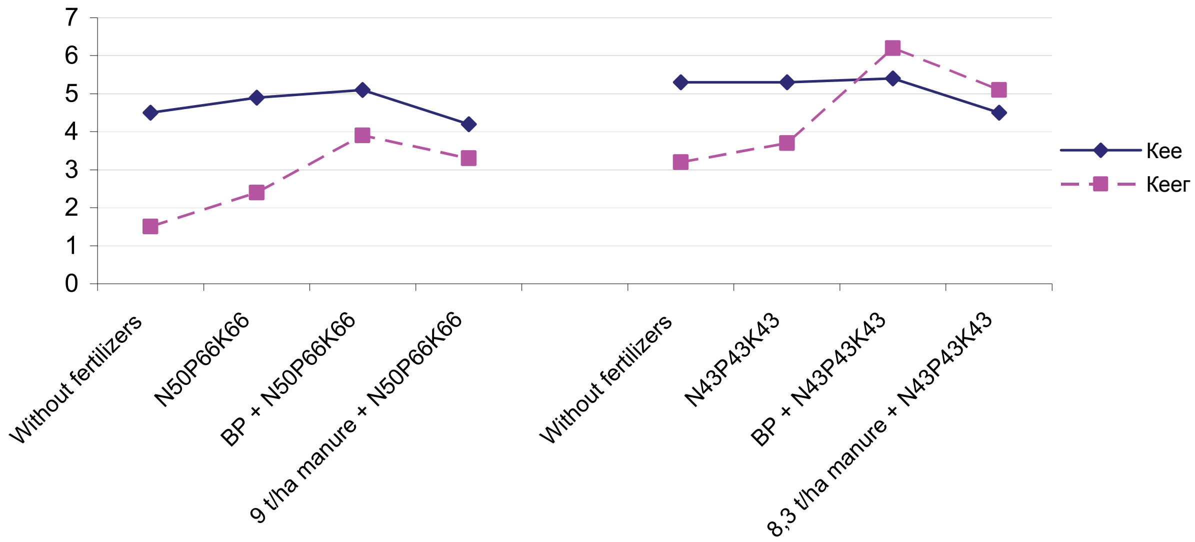

Fig. 1. Energy efficiency of agro-technologies with excluding (Kee) and including (Keeг) changes of soil energy balance, BTRSS, 1996-2012 years

Note: BP – by-products

Organic-mineral system of fertilizers by ecology-energy evaluation was determined more efficient. Joint applying manure and fertilizers increased energy capacity of the yield of growing crops on the fond of improving energy balance in soil and in comparing to fertilizers application raised Keer in ten fields rotation – on 0,9-1,5, six fields – on 1,4-2,5.

The most energy efficient was recognized the system of fertilizers that combined applying fertilizers and by-products. Absence of additional expanses for plowing by-products into soil and significant improve energy balance in the soil provided the highest indexes Keer: in ten fields rotation – 3,9, six fields – 6,2. In comparing to traditional organic-mineral system of fertilizers Keer in ten fields rotation raised – on 0,6, six fields – on 1,1, that was got at the expanse of decrease of energy expenditures on manure application. By gradation Yu.O. Tarariko in six fields' rotation it was got the highest energy efficiency of agro-technology.

Conclusions

1. The most energy efficient was determined an alternative organic-mineral system of fertilizers ($N_{43\text{-}50}P_{43\text{-}66}K_{43\text{-}66}$ + by-products on 1 ha of rotation area): energy expenses – 22,8-27,9, yield energy capacity – 122,3-140,9 GJ/ha of rotation, Kee – 5,1-5,4, Keer – 3,9-6,2.

2. Applying traditional on the fond of manure system of fertilizers ($N_{43\text{-}50}P_{43\text{-}66}K_{43\text{-}66}$ + 8,3-9 t manure per 1 ha of rotation) did not provide significant increase crops rotation productivity (129,8-146,7 GJ/ha of rotation area), and sharply increased energy costs (28,6-34,7 GJ/ha of rotation area), that result into the decrease of Kee – to 4,2-4,5, Keer – to 3,3-5,1. Per one GJ of energy expenses for manure application the increase of yield in an average for both crops rotations equaled 1,7-1,9 GJ/ha.

3. Applying only fertilizers ($N_{43\text{-}50}P_{43\text{-}66}K_{43\text{-}66}$ on 1 ha of rotation area) caused significant loss of soil energy (18,0-23,9 GJ/ha), that decreased of energy efficiency of agro-technologies: energy expenses – 22,3-27,2, yield energy capacity – 117,6-134,3 GJ/ha of rotation, Kee – 4,9-5,3, Keer – 2,4-3,7. Per one GJ of energy expenses for fertilizers application the increase of yield in an average for both crops rotations equaled 5,2-5,5 GJ/ha.

4. The highest energy efficiency of agro-technologies was got in ten fields crops rotation by applying $N_{43}P_{43}K_{43}$ + by-products on 1 ha of rotation area: Kee – 5,4, Keer – 6,2. Decrease in six fields rotation in comparing to ten fields the share of sugar beet from 30 to 16,7% and increase share of legumes from 10 to 33% raised Kee and Keer: by applying fertilizers – reciprocally on 0,4 and 1,3, by alternative organic-mineral system of fertilizers – on 0,3 and 2,3, traditional – on 0,3 and 1,8. Energy balance in six fields rotation in comparing to ten fields improved on 12,1-16,6 GJ/ha.

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