ENERGETIC ESTIMATION OF WINTER WHEAT NITROGEN FERTILIZING AFTER DIFFERENT TYPES OF FORECROPS

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The research was based on precise two-part experiments, held for years with winter wheat. First factor: forecrop winter – rape, pea; second factor: four levels of fertilizing N 30, 60, 90 and 120 kg per hectare. In the years 1994–1998 the amount of crops and energetic value of yield were estimated, as well as energetic efficiency of expenditure of material, labor, and mechanical force expenditure. The above mentioned factors made the basis for the energetic balance, energy consumption and energetic efficiency calculation. The obtained results reveal the relatively high amount of energy used for fertilization (from 36.2% with the dosage of N = 30 kg/ha up to 57.6% with 120 kg N/ha). The most advantageous energy consumption parameters of winter wheat production were obtained with pea as forecrop and 30 kg N fertilizing. The highest energy consumption, lowest cost-effectiveness and least advantageous energy consumption parameters were observed after rape as a forecrop and high dosage of nitrogen fertilization (90 and 120 kg/ha).

winter wheat; nitrogen fertilization; forecrop; material force expenses; labor and mechanical force expenses; energetic value of yield; energy consumption (per unit); energetic efficiency (index)

INTRODUCTION

Mineral fertilization is still considered to be the main yield-producing factor, as well as an important component of current economic and energy expenses in agriculture despite a recent decrease in using this type of fertilizers.

Winter wheat is known as a plant highly reacting to a forecrop and nitrogen fertilization (Fotyma, Fotyma, 1993; Kus, Jonczyk, 1993; Suwara, Gawronska-Kulesza, 1995; Szmigiel, 1994). But crop increase very often does not compensate the increase of the fertilizer dosage. So, in a changing economic situation appears the question of fertilizing profitability (if any at all). In the recent years of agricultural profitability decline the economic analysis in this branch is of great importance.

But the above mentioned analysis is quite often limited to the production criteria only. Energy calculation should be taken into consideration as one of the main parameters of such analysis. Reasons for this calculation are mentioned by a number of authors (Blazek, 1990; Birski, Kreft, 1994; Kus et al., 1992; Budzynski et al., 1996; Wielicki, 1989; Wójcicki, 1983). One of the advantages of this method is the possibility to compare results despite the price rate, as well as, using its figures in complex estimation (Blazek, 1990; Wielicki, 1989).

Energy calculation enables production improvement through the increase of cost efficiency. The results of 1989 study by Harasim show that energetic efficiency factor is closely and positively correlated with profitability figures.

There are not too many examples to energetic research in the literature. From the existing studies it appears, that industrial production means extension results in reduction of energetic efficiency (Budzynski et al., 1996; Harasim, 1989; Szemplinski, 1989; Szemplinski, Budzynski, 1994; Wróbel, Budzynski, 1994; Wielicki, 1986).

Our study attempts to analyse energetic efficiency of winter wheat production depending on the forecrop and the dosage of nitrogen fertilizers.

MATERIAL AND METHODS

The research has been based upon the figures of steady exact crop rotary system experiment, held on the Experimental Field of Cultivation Department in Agricultural Research Institute in Chylice near Warsaw. The experiment took place in 4 repetitions at split-plot, on black earth of the following granulometric composition: light clay pH = 6.7; C org = 1.12%; N org = 0.118% assimilable phosphones P_2O_5 = 24.8 mg/100 g of soil and assimilable potassium K_2O = 12.7 mg/100 g of soil.

The examined factors are winter wheat forecrop: A – winter rape, B – sowing peas and 4 levels of nitrogen fertilization of the wheat: N_1 – 30 kg/ha, N_2 – 60 kg/ha, N_3 – 90 kg/ha and N_4 – 120 kg/ha. Nitrogen was applied as ammonium nitrate (34% N) in two or three terms, but phosphates (triple superphosphate P_2O_5) and potassium (potassium salt 56% K_2O) were applied before sowing of winter wheat and the dosage had not been differentiated (Table I).

The present study estimates energy calculation of winter wheat production according to the forecrop and the dosage of nitrogen fertilizer. The figures of 5-year period (1994–1998) winter wheat crops, transformed into cereal units, were used. Labor force expenses and tractive force expenses were estimated

I. Doses of fertilizers for winter wheat

Fertilization	Term	Doses			
		N_1	N_2	N_3	N_4
N	I – in autumn before sowing	15	20	20	20
	II – in spring after starting vegetation	15	40	40	60
	III – at the beginning of shooting	–	–	30	40
P_2O_5	before sowing	80			
K_2O	before sowing	100			

as the sum total of all the actions performed. These are cultivation, harvesting and transporting of the agricultural products. Material force calculation was based on actual sowing expenditure, amount of mineral fertilizers and plant protection agents used per one ha. Production expenditure, labor force and tractive force were transformed into MJ, using the indexes of energy consumption, that are used for energetic calculation of crops (Wójcicki, 1983; Wielicki, 1986).

The following parameters were used for energetic estimation of the wheat production technology:
- gain of cumulative energy (MJ/ha); this is the result of a substraction of energetic value of the yield (Pe) and total input of the yield (Ne)
- energy consumption per unit per 1 ton of cereal
- index of energetic efficiency ($Ee = Pe/Ne$)

Energetic value of a combine harvester:
(1) the weight of the combine ZO56 = 7 200 kg = A
(2) used time (hours) = 3 000 h = B
(3) the weight of the combine per hour = C
C = A/B = 7200 kg/3000 h = 2.4 kg/h
Value of used parts (D) = 1.44 kg/h
D = C x 60%
Energetic value of the combine = 2.4 kg/h x 112 MJ + 1.44 kg/h x 80 MJ = 268.8 MJ/h + 115.2 MJ/h = 384 MJ/h

Fuel consumption of the combine and energetic value:
Fuel consumption = 15.6 l/h x 0.93 = 12.9 kg/h
L = 12.9 kg/h x 48 MJ = 619.2 MJ/h
Energetic value of a combine-hour (kbh)
kbh = K + L
kbh = 384 MJ/h + 619,2 MJ/h = 1 003 MJ/h

Energetic value of the tractor:

(1) the weight of the tractor (Mc) = 1 200 kg

(2) using time (hours) (Lhc) = 12 000 h

(3) the weight of the tractor per hour (Q)

$$Q = \frac{Mc}{LHc} \frac{1\,200\text{ kg}}{12\,000\text{ h}} = 0.1\text{ kg/h}$$

(4) Value of user parts Q x 60% = 0.1 x 0.6 = 0.06 kg/h

(5) Energetic value

0.1 kg/h x 112 MJ + 0.06 kg/h x 80 MJ = 11.2 MJ/h + 4.8 MJ/h = 16 MJ/h

(6) Energetic value of a tractor-hour c.n.h.

hard labor – 423 MJ/h

medium – 270 MJ/h

light – 167 MJ/h.

Fuel consumption of the tractor C-360:

(1) Hard labor: first ploughing, cultivating etc.

A) maximal fuel consumption = 10.6 kg/h

B) power usage = 55–80%

C) energetic value of oil 1 kg = 48 MJ

D) energetic value of the tractor = 16 MJ

Fuel consumption = 10.6 kg/h x 0.8 = 8.48 kg/h

Energetic value c.n.h. (A) = energetic value of the tractor (B) + energetic value of fuel used C

A = 16 MJ + 407.04 MJ/h

A = 423.04 MJ/h = appr. 423 MJ

(2) Medium labor: harrowing, fertilization, cultivation, sowing, road transporting

A) maximal fuel consumption = 10.6 kg/h

B) power usage = 30–50%

Fuel consumption = 10.6 kg/h x 0.5 = 5.3 kg/h

A = 16 MJ + 254.4 MJ/h = 270.4 MJ/h = appr. 270 MJ/h

(3) Light labor: transporting and machines

C) maximal fuel consumption = 10,6 kg/h

D) power usage = up to 30%

Fuel consumption = 10,6 kg/h x 0,3 = 3,18 kg/h

A = 16 MJ + 152.64 MJ/h = 168.64 MJ/h = appr. 167 MJ/h

RESULTS AND DISCUSSION

Material force expenses

Material force expenses consist of sowing material, mineral fertilizers (nitrogen, phosphates, potassium), plant protecting agents (Tables II and III). These expenses differ only in a nitrogen fertilization level and the forecrop does not differentiate material force expenses.

The structure of energy expenses has been changed according to nitrogen fertilizer dosage. Nitrogen fertilizers make 31.4% of energy expenses if 30 kg/ha, but up to 67.4% if 120 kg/ha.

It should be taken into consideration that the main amount of material force expenses expressed in MJ are spent on fertilizers, first of all nitrogen ones. That makes sense of usage of forecrop which enable decrease of nitrogen

II. Energetic value of material force expenses

Specification	Quantity	Energy equivalent	Energetic value	% structure for levels of nitrogen fertilization			
	kg/ha	kg/MJ	MJ	N_1 = 30 kg	N_2 = 60 kg	N_3 = 90 kg	N_4 = 120 kg
Seeds	260	7.5	1 950	28.7	21.43	17.09	14.21
Mineral fertilizers							
Nitrogen	30*	77	2 310	34.06	x	x	x
	60*	77	4 620	x	50.82	x	x
	90*	77	6 930	x	x	60.8	x
	120*	77	9 240	x	x	x	67.4
Phosphate	80*	14	1 120	16.50	12.31	9.81	8.16
Potassium	100*	10	1 000	14.73	10.99	8.76	7.29
Pesticides							
Chwastox D	0.89*	300	267	3.93	2.93	2.34	1.94
Zaprawa nasienna	0.338*	300	101.4	1.50	1.11	0.88	0.73
Funaben							
Tilt	0.125**	300	37.5	0.55	0.41	0.32	0.27
				6 785.9 MJ	9 095.9 MJ	11 405.9 MJ	13 715.9 MJ

fertilizer doses, not reducing the crops themselves. These results are widely confirmed in the literature (B u d z y n s k i et al., 1996).

Mechanical force and labor force expenses

Mechanical and labor force expenses per ha of winter wheat production are identical if fertilized by N_1 (30 kg/ha) and by N_2 (60 kg/ha) (Table IV). Then there are two nitrogen fertilizing rides, and it makes 7 438.4 MJ/ha. But they are higher if nitrogen is applied in three rides and make 7 748.4 MJ/ha for N_3 and N_4 (Table V).

The dominant place in the structure of labor and mechanical force expenses of winter wheat production is taken by cultivation and harvesting expenses. Similar results are also shown in some other studies (B u d z y n s k i et al., 1996; Z a w i s l a k, R z e s z u t e k, 1992).

The forecrop does not differentiate labor and mechanical force expenses as the production process of winter wheat is identical after both winter rape and sowing pea.

Energy consumption of winter wheat production with different dosages of nitrogen fertilizers

Energy consumption of winter wheat with different nitrogen fertilizer doses was strictly different (Table VI). This is caused by fertilization. The

III. Material force expenses

Specification	Level of nitrogen fertilizing							
	N_1 = 30		N_2 = 60		N_3 = 90		N_4 = 120	
	energetic value MJ	%	energetic value MJ	%	energetic value MJ	%	energetic value MJ	%
Seeds	1 950	28.73	1 950	21.43	1 950	17.09	1 950	14.21
Nitrogen fertilizers	2 310	34.06	4 620	50.82	6 930	60.80	9 240	67.40
Phosphate fertilizers	1 120	16.50	1 120	12.31	1 120	9.81	1 120	8.16
Potassium fertilizers	1 000	14.73	1 000	10.99	1 000	8.76	1 000	7.29
Pesticides:								
Chwastox D	267	3.93	267	2.93	267	2.34	267	1.94
Zaprawa nasienna Funaben	101.4	1.50	101.4	1.11	101.4	0.88	101.4	0.73
Srodek grzybobójczy Tilt	37.5	0.55	37.5	0.41	37.5	0.32	37.5	0.27
Σ	6 785.9		9 005.9		11 405.9		13 715.9	
%	100		134		168		202	

IV. Mechanical force and labor force expenses per 1 ha (N_1 = 30, N_2 = 60 kg)

Specification	Quantity	Energy equivalent	Energetic value	Quantity	Energy equivalent	Energetic value	Energetic value
	rbh	rbh	rbh	cnh	cnh/MJ	cnh	cnh + rbh
		MJ	MJ		MJ	MJ	MJ
Skimming	2.0	40	80	2.0	423	846	926
Harrowing	0.9	40	36	0.9	270	243	279
Fertilization K_2O, P_2O_5, N	1.5	40	60	1.3	270	351	411
Ploughing + rolling	3.0	40	120	3.0	423	1 269	1 389
Harrowing	0.9	40	36	0.9	270	243	279
Sowing	2.5	40	100	2.5	270	625	725
Using of herbicide	1.2	40	48	1.0	270	270	318
Spring fertilization (N_1 + N_2)	1	40	40	1	270	270	310
Plant protection	1.2	40	48	1	270	270	318
Harvest	1.8	40	72	1.8*	1003*	1 805.4	1 877.4
Grain transport	3.0	40	120	1.8	270	486	606
Σ total	19		760	17.2		6 678.4	7 438.4

V. Mechanical force and labor force expenses per 1 ha (N_3 = 90, N_4 = 120 kg N/ha)

Specification	Quantity	Energy equivalent	Energetic value	Quantity	Energy equivalent	Energetic value	Energetic value
	rbh	rbh	rbh	cnh	cnh/MJ	cnh	cnh + rbh
		MJ	MJ		MJ	MJ	MJ
Skimming	2.0	40	80	2.0	423	846	926
Harrowing	0.9	40	36	0.9	270	243	279
Fertilization K_2O, P_2O_5, N	1.5	40	60	1.3	270	351	411
Ploughing + rolling	3.0	40	120	3.0	423	1 269	1 389
Harrowing	0.9	40	36	0.9	270	243	279
Sowing	2.5	40	100	2.5	270	625	725
Using of herbicide	1.2	40	48	1.0	270	270	318
Spring fertilization (N_3 + N_4)	2*	40	80	2*	270	540	620
Plant protection	1.2	40	48	1	270	270	318
Harvest	1.8	40	72	1.8**	1 003**	1 805.4	1 877.4
Grain transport	3.0	40	120	1.8	270	486	606
Σ total	20		800	18.2		6 948.4	7 748.4

VI. Input of cumulative energy for particular element of winter wheat production in MJ per ha related to nitrogen fertilization

Production operation	Variant of N fertilization							
	N_1		N_2		N_3		N_4	
	$MJ.ha^{-1}$	%	$MJ.ha^{-1}$	%	$MJ.ha^{-1}$	%	$MJ.ha^{-1}$	%
Soil tillage	2 594.0	18.2	2 594.0	15.7	2 694.0	13.5	2 594.0	12.1
Fertilization NPK	5 151.0	36.2	7 461.0	45.1	10 081.0	52.6	12 391.0	57.7
Sowing	2 954.0	20.8	2 954.0	17.9	2 954.0	15.4	2 954.0	13.8
Plant protection and weeding	1 041.9	7.3	1 041.9	6.3	1 041.9	5.5	1 041.9	4.9
Harvest and transport	2 483.4	17.5	2 483.4	15.0	2 483.4	13.0	2 483.4	11.5
Total	1 4224.3	100.0	16 534.3	100.0	19 154.3	100.0	21 464.3	100.0
Total material including	6 785.9	47.7	9 095.9	55.0	11 405.9	59.6	1 315.9	63.9
Inputs of human labor and mechanization	7 438.4	52.3	7 438.4	45.0	7 748.4	40.4	7 748.4	36.1
Total	14 224.3	100.0	16 534.3	100.0	19 154.3	100.0	21 464.3	100.0

highest expenses were during the highest fertilizer doses of 120 kg/ha. With reduction of nitrogen doses energy expenses are reduced, too. It should be pointed out, that energy spent on fertilizing NPK of winter wheat made from 57.7% of all the expenses while using N4, down to 36.2% with the lowest dose of nitrogen. The stream-structure of energy expenses displays the fact that in all the experiments from 47.7 to 63.9% of energy was applied in materials.

The least energy expenses in winter wheat production make cultivation and plant protection.

The cultivation energy expenses make only 7.3–4.9% of all the expenses.

Energetic efficiency of winter wheat production after different forecrop and different dosages of nitrogen fertilizers

Analysing the amount of crop in the form of cereal units, as well as energy units it was found that winter wheat production after peas is much higher than the one after winter rape (Table VII). It is worth saying that the similar crops of wheat were reached after peas with fertilizing 30 kg/ha and rape with 120 kg/ha fertilizing level. This configuration of expenses, energy and crops caused that energy consumption per unit with 30 kg/ha and peas as forecrop of wheat was very advantageous and quite low (2 746.0 MJ/ton of wheat

VII. Energetic efficiency of winter wheat production growing related to forecrops and mineral nitrogen fertilization doses (mean 1994–1998)

Forecrop	Doses of N	Grain yield	Energetic value of yield	Total input	Gain of cumulative energy	Energy consumption per unit	Index of energetic efficency
			MJ/ha		MJ/ha	MJ/t	
	kg/ha	dt/ha	Pe	Ne	Pe – Ne	Ne/yield	Pe/Ne
Winter rape	30	42.1	31 575	14 224.3	17 350.7	3 378.7	2.22
	60	43.2	32 400	16 534.3	15 865.7	3 827.4	1.96
	90	49.1	36 825	19 154.3	17 670.7	3 901.1	1.92
	120	51.8	38 850	21 464.3	17 385.7	4 143.7	1.81
	$\bar{x}$	46.6	34 950	17 844.3	17 105.7	3 829.3	1.96
Pea	30	51.8	38 850	14 224.3	24 625.7	2 746.0	2.73
	60	55.3	41 475	16 534.3	24 940.7	2 989.9	2.51
	90	58.3	43 725	19 154.3	24 570.7	3 285.5	2.28
	120	58.9	44 175	21 464.3	22 710.7	3 644.2	2.06
	$\bar{x}$	56.1	42 075	17 844.3	24 230.7	3 180.8	2.36

cereal). Each higher level of nitrogen fertilization after both above mentioned forecrops worsened this parameter due to the fact that increase of crops did not compensate the increase of fertilizing expenses.

The energetic efficiency index, being the ratio of cumulative crop energy and energy expenses, was the most advantageous in configuration of peas as a forecrop 30 kg/ha fertilization and made 3.54 (2.73). The worst index was obtained by rape as a forecrop and high dosages of nitrogen fertilization (N_3 and N_4).

This analysis droves to a conclusion that peas (a papilionaceous plant) enables reduction of costs and energy expenses for production of 1 ton of cereal, and obtaining the best value of energetic efficiency index. Furthermore, we can conclude that during increased mineral fertilization mainly nitrogen one the energy expenditure goes up and the energetic efficiency index remains on a quite low level. The energetic analysis results appeared to be similar to economic analysis and results of other researchers (K u s et al., 1992; B u d z y n s k i et al., 1996; W i e l i c k i , 1986).

CONCLUSION

1. Energy spent on fertilizing NPK of winter wheat is high, made from 57.7% of all the expenses while using N_4, down to 36.2% with the lowest dose of nitrogen.
2. Energy and crops caused that energy consumption per unit with 30 kg/ha and pea as forecrop of wheat is very advantageous and quite low. Each higher level of nitrogen fertilization worsened this parameter due to the fact that increase of crops did not compensate the increase of fertilizing expenses.
3. The forecrop pea fertilized with 30 kg/ha N will provide the same yield of winter wheat grain as that of wheat after forecrop winter rape, but applied a dose of 120 kg/ha N. The forecrop pea can save about 7 200 MJ/ha energy in comparison with winter rape (Table VI).

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Energetický odhad dusíkatého hnojení ozimé pšenice po různých typech předplodiny.

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Výzkum byl založen na přesných pokusech vedených s ozimou pšenicí během řady let. První faktor: předplodiny pšenice – řepka, hrách; druhý faktor: čtyři stupně hnojení dusíkem – 30, 60, 90 a 120 kg/ha. V letech 1994–1998 byly stanoveny výnos a energetická hodnota výnosu a rovněž energetické vklady výrobků, práce a strojů. Tyto faktory vytvořily základ pro výpočet energetické bilance, spotřeby energie a energetické účinnosti. Získané výsledky ukázaly, že vysoké množství energie je vkládáno hnojením (od 36,2 % při dávce dusíku 30 kg/ha do 57,6 % při dávce 120 kg/ha). Nejvhodnější parametry spotřeby energie u ozimé pšenice byly získány po předplodině hrachu a při hnojení 30 kg dusíku na hektar. Nejvyšší spotřeba energie, nejnižší energetická účinnost a nejméně výhodné parametry spotřeby energie byly zjištěny po předplodině řepce a při vysokých dávkách dusíku (90 a 120 kg/ha).

ozimá pšenice; hnojení dusíkem; předplodina; náklady materiální povahy; pracovní náklady a výdaje na mechanizaci; energetická hodnota výnosu, spotřeba energie (na jednotku), energetická účinnost (index)

(Překlad abstraktu do češtiny byl pořízen v redakci časopisu.)

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