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USE OF AGRICULTURAL AND COMMUNAL WASTE PRODUCTS IN FERTILIZATION OF OILSEED RAPE GROWN FOR BIOFUEL

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Summary. Seeds of three double zero oilseed rape population cultivars and 1 hybrid cultivar, grown in two field experiment, made up the material for our tests. The aim was to compare the effect of agricultural waste products (FYM, slurry) and sewage sludge. In experiment 1, where traditional fertilizers were applied (FYM, slurry, mineral fertilizers), depending on a cultivar and fertilization system, rape seeds contained on average from 46.22 to 47.97% of fat. Each type of organic as well as organic and mineral fertilization resulted in an increase of the oil concentration in seeds. In experiment 2, seeds of winter oilseed rape cv. Californium from objects fertilized with 10 t d.m. ha^{-1} (2004) of sewage sludge composted with straw (Biohum) and sewage sludge alone (Tyrowo) contained on average over 50% of crude oil. The crude oil yield depended on the volume of seed yield. FYM fertilization as well as application of various sewage sludge-based composts increased the yield of oil by over 2.5 t per ha, on average. Mineral fertilization, fertilization with a high rate of slurry or a single rate of sewage sludge increased the ratio of saturated fatty acids. In contrast, FYM and double application of sewage sludge in rotation increased the proportions of mono- and poly-unsaturated fatty acids.

Key words: fertilization, winter oilseed rape, oil, fatty acids

INTRODUCTION

Oilseed plants are not only one of the major sources of energy found in human food and animal fodder, but they are also a valuable raw material for many industrial products [Rzepak… 2002].

In the world's production of oilseed crops, oilseed rape is the second to soybean [Hulsbergen and Kalk 2001, Faber 2002]. The global output of oilseed rape production, according to the Oil World data, was over 48 million tons in 2005/2006 [Rosiak 2005]. In the EU, oilseed rape made up 73.1% of the total oilseed crops production in 2005. The biggest producers of this crop are Germany and France, with Poland being the fourth largest producer (1.45 million tons). Interest in oilseed rape in the world is stimulated by its possible use as diesel fuel, including fuel to run compression-ignition engines [Richards 2000, Bartkowiak-Broda and Mikołajczyk 2003, Tys *et al.* 2003, Podkówka (red.) 2004, Jankowski *et al.* 2005, Kuś 2006]. In the nearest future, the estimated demand for rape seed oil used to produce biodiesel fuel will be increasing by 3-4 tons annually.

Rape seed oil methyl esters, i.e. first generation biofuels, are used for a number of reasons, such as: protecting natural environment, securing energy safety and searching for new agricultural production areas and markets for agricultural produce [Kwiatkowski and Żółtowski 2003, Piekarski and Wawrzosek 2004]. At present, legal solutions are being introduced to regulate the use of fatty acid methyl esters as fuel additives. The EU directive issued in 2003 imposed the obligation to use biofuels in transport from 5.75% in 2010 to 20% in 2020 [Skręt *et al.* 2006].

Both traditional fertilizers (mineral or natural) and bio-waste (sewage sludge, municipal waste) are allowed to be used in cultivation of oilseed rape for non-consumption purposes. The use of bio-waste in cultivation of crops for technical purposes seems particularly recommendable in view of sustainable development. Bio-waste utilization makes it possible to eliminate or at least drastically reduce amounts of waste and to reduce unit costs of production of industrial crops [Kaczor *et al.* 2003a, b]. As regards natural fertilizers, slurry can be applied to fertilize oilseed rape for technical purposes. Utilization of slurry is an essential problem for large animal farms [Mazur and Sądej 1999, Mazur *et al.* 2002].

The aim of this paper was to assess the effect of waste produced on a farm (FYM, slurry) and communal waste (sewage sludge) on the composition and yield of oil obtained from oilseed rape grown for technical purposes (biofuels and bio-components) as well as modifications in the composition of fatty acids.

MATERIAL AND METHODS

The material for our tests consisted of rape seeds from double zero population (Ceres – 1990, Lirajet – 1997, Californium – 2006) and hybrid (Kaszub F_{1z} 2004) cultivars, which were obtained from two field trials carried out at the Production and Experimental Farm in Bałcyny near Ostróda.

Experiment 1 was established in 1972. Its objective was to compare the influence of three fertilization systems; organic fertilization (FYM, slurry), mineral fertilization and mixed organic-mineral fertilization. Liquid manure was applied in two rates. Each year, rate I was balanced with FYM and mineral fertilizers in terms of the amounts of nitrogen introduced to soil. The volume of rate II was determined so as to maintain the quantity of organic carbon added to soil on the same level as the amount of carbon comprised in a rate of FYM. The experiment also included objects in which natural fertilization was supplemented with phosphorus-potassium fertilizers. The latter were applied at a rate equivalent to half the content of those nutrients introduced in the mineral fertilization system. The quantities of nutrients introduced to soil with the fertilizers (annual means) are reported in Tab 1. The crops in the above field experiment were grown in a 7-year rotation system. The paper contains the results of the experiment pertaining to the years 1990-2004.

Table 1. Rates of organic fertilizers and components N, P, K applied to soil with fertilizers (means for 1972–2004)

Fertilization	Rate	N	P	K
	$t \cdot ha^{-1}$	$kg \cdot ha^{-1}$		
Slurry rate I	41.2	112	41.8	123.1
Slurry rate I + PK	41.2	112	61.2	174.8
Slurry rate II	74.8	209	75.3	220.0
Slurry rate II + PK	74.8	209	94.7	271.7
Farmyard manure	22.4	112	37.8	96.6
Farmyard manure + PK	22.4	112	57.2	148.3
NPK	-	112	38.3	107.0

Experiment 2 was set up in 2004. Composts from pre-fermented sewage sludge (Tyrowo), dried and granulated sewage sludge (Polepszacz) and sludge mixed with straw (Biohum) were used as fertilizers. The composts were applied in single treatments at a rate of 10 t d.m. ha^{-1} (2004) or in two treatments in a rotation system, 5 t d.m. ha^{-1} each treatment. Comparisons were made with the control object (without fertilization) and the object fertilized exclusively with NPK. In all the objects nitrogen rates were balanced by supplementing amounts of this element from mineral fertilizers. In this experiment, crops were grown in a 4-year rotation system. Samples of the composts were taken to be averaged and used for determination of dry matter and N, P and K with the standard methods (Tab. 2).

Table 2. Content of dry matter and macroelements in bio-waste (% d.m.)

Specification	Biohum	Polepszacz	Tyrowo
d.m.	58.68	85.14	49.31
N	1.07	1.88	4.66
P	0.75	1.28	2.99
K	0.13	0.18	0.25

In both experiments, yield of seeds was assessed after oilseed rape harvest. The concentration of crude fat in seeds was determined by light petroleum ether extraction on a Soxlet apparatus. The extracted fat was used to determine composition of fatty acids by gas chromatography on a 6890N Agilent chromatograph with a flame ionizing deterctor (FID). The results of the determinations (from each plot) underwent analysis of variance to assess significance of differences between the experimental factors at the level of significance $p = 0.05$.

RESULTS AND DISCUSSION

It is possible to improve yielding of oilseed rape grown for non-consumption purposes by cultivating hybrid varieties, introducing resistance to diseases, pests, drought, frost and by modifying the plant's phenotype in order to reduce its susceptibility to lodging and shattering. Fertilization is another essential element of yield improvement, as oilseed rape has very high nutritional and fertilization demands [Rzepak… 2002].

In experiment I, which was based on traditional fertilizers (FYM, slurry, mineral fertilizers), rape seeds contained on average from 46.22 to 47.97% of fat, depending on a cultivar and fertilization system. Each type of organic and organic-mineral fertilization increased fat content, although a statistically significant increment was obtained only in the cultivation of the hybrid variety Kaszub F_{1Z} (Tab. 3).

Table 3. Composition and yield of fat in seeds of oilseed rape supplied with natural and mineral fertilizers, % d.m.

Fertilization	% fat				Yield of fat $t \cdot ha^{-1}$			
	Years of investigation			Mean	Years of investigation			Mean
	1990	1997	2004		1990	1997	2004	
	Varieties				Varieties			
	Ceres	Lirajet	Kaszub F_1z		Ceres	Lirajet	Kaszub F_1z	
I. No fertilization	45.44	48.31	44.91	46.22	0.99	0.87	1.26	1.04
II. Slurry rate I	47.07	48.71	45.28	47.03	1.84	1.22	1.72	1.59
III. Slurry rate I + PK	46.26	49.05	46.13	47.15	1.77	1.27	1.94	1.66
IV. Slurry rate II	44.67	46.89	45.97	45.87	1.98	1.27	1.70	1.65
V. Slurry rate II + PK	45.27	47.32	47.12	46.57	2.03	1.32	1.93	1.76
VI. Farmyard manure	47.11	48.57	47.14	47.61	2.32	1.70	2.31	2.11
VII. Farmyard manure +PK	47.20	48.70	48.04	47.97	2.61	1.85	2.31	2.26
VIII. NPK	45.20	48.13	45.12	46.15	1.76	1.49	2.16	1.80
LSD p = 0.05	1.62	1.05	1.14	1.27	0.33	0.25	0.21	0.26

Cultivars Ceres and Kaszub F_{1Z} responded more positively to FYM fertilization than to slurry applied in rate I and balanced with manure in terms of nitrogen added to soil. As for cv. Lirajet, the effect of both fertilizers was comparable. The application of slurry in rate II, balanced with manure in terms of the amounts of organic carbon added to soil, resulted in a decrease in the content of crude fat in rape seeds compared the effect obtained after FYM application. This rate added twice as much nitrogen as the other fertilizers, which seems to suggest that a high rate of slurry depressed the concentration of fat in seeds. A similar opinion was expressed by other authors [Jeżowski 2001, Wójtowicz 2004].

In experiment 2, seeds of winter cultivar Californium harvested from objects fertilized with 10 t d.m. ha^{-1} (2004) composted with sewage sludge mixed with straw (Biohum) and sewage sludge alone (Tyrowo) contained on average over 50% crude fat (Fig. 1).

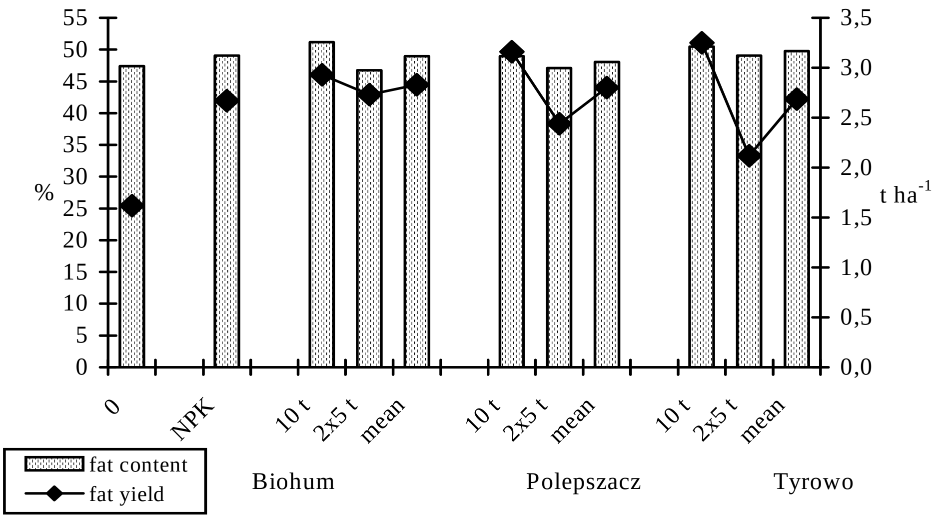


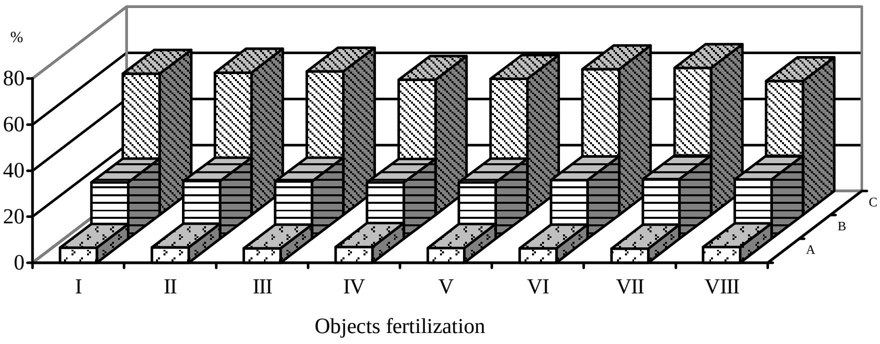
Fig. 1. Effects of sludge dose on fat content and fat yield

On the other hand, dividing the rate of each compost into two rates (5 t d.m. ha^{-1} in 2004 and 5 t d.m. ha^{-1} immediately before oilseed rape) caused a decline in the fact content in seeds down to 47.63% on average. A significant decrease in the content of fat (46.7%) in seeds originating from Biohum-fertilized objects could have been caused by the need to balance the spring rate of nitrogen. Negative correlation between the spring rate of nitrogen and fat concentration in yield was also demonstrated by Jankowski et al. [Jeżowski 2001].

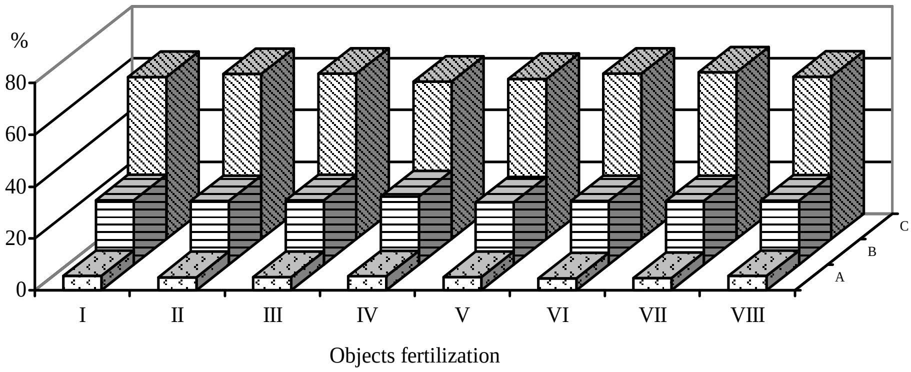
The yield of crude oil from any of the cultivars grown in experiment 1 was clearly dependent on fertilization. Compared to the control object, any fertilization system resulted in statistically proven increase in crude oil yield (Tab. 3). When using fertilizers in rates balanced with the amount of nitrogen added to soil, the highest yield of fat was obtained following manure fertilization. The effect of slurry applied in rate II was comparable to that achieved after fertilization with slurry in rate I and mineral fertilizers.

Also in experiment 2, in which sewage sludge was applied, the yield of crude fat was correlated with fertilization (Fig. 1). The average yield from the objects where oilseed rape was grown three years after application of the composts (10 t d.m. ha^{-1}) exceeded 3.2 t per ha. In contrast, the immediate effect of fertilizing oilseed rape with any of the composts caused a decline in the yield of crude oil by 29%.

The value of oilseed rape for non-consumption purposes (biofuels, bio-components) can be improved not only by increasing the concentration of fat in its seeds, but also through modification of the composition of fatty acids. The objective is to increase the share of non-saturated fatty acids, which possess higher energy value [Spasibionek 2002, Bartkowiak-Broda and Mikołajczyk 2003].



A – saturated fatty acids – NIR_{005} – 0,09;
B– poly – unsaturated fatty acids – NIR_{005} – 0,51;
C– mono – unsaturated fatty acids – NIR_{005} – 0,80

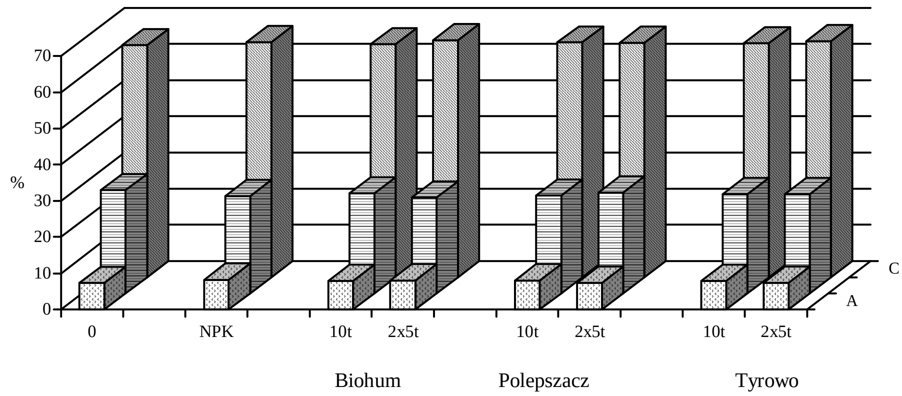


I – VIII objects fertilization explanations see Table 3:
A – saturated fatty acids – NIR_{005} – 0,06;
B – poly – unsaturated fatty acids – NIR_{005} – 0,47;
C – mono – unsaturated fatty acids – NIR_{005} – 0,72

Fig. 2. Effect of manure, slurry and mineral fertilization on percentage of fatty acids in rape seed oil

Our trials show that proportions of particular fatty acids was mainly related to a winter oilseed rape cultivar. Higher percentages of non-saturated (by 1.29% on average) and poly-unsaturated fatty acids (by 0.24%) were found in cv. Lirajet seeds compared to cv. Kaszub F_{1Z}. Reverse proportions were demonstrated in the case of mono-unsaturated fatty acids. Fertilization modified the concentration of every group of fatty acids, although the changes were not always statistically proven. The average content of saturated fatty acids ranged between 5.40 and 6.14%. The highest statistically significant increase in the concentration of saturated fatty acids was obtained in both cultivars when mineral fertilizers and slurry in rate II were applied; much lower percentage of those acids occurred in seeds of rape grown on manure fertilized objects.

The share of mono-unsaturated fatty acids in oil varied from 58.69 to 64.34% while that of poly-unsaturated fatty acids ranged from 24.48 to 26.37% (Fig. 2). Manure increased the concentration of those acids in seeds of both tested cultivars more strongly than the other types and rates of fertilizers. Application of supplementary phosphorus-potassium fertilization together with natural fertilizers resulted in lower concentrations of saturated fatty acids, and generally increased the content of mono- and poly-unsaturated ones.



A – saturated fatty acids
B – poly – unsaturated fatty acids
C – mono – unsaturated fatty acid

Fig. 3. Effects of sludge dose on percentage of fatty acids in rape seed oil

The population cultivar Californium, as compared to cv. Lirajet and Kaszub F_{1Z}, was characterised by higher contribution of both saturated (7.33-8.11%0, mono-unsaturated (64.01-65.49%) and mono-unsaturated fatty acids (26.51-28.58%) in seed oil. As the demand for oil of modified proportions of fatty acids is on the increase, it seemed more profitable (within the limits of a statistical error) to apply the composts in a rotation system rather than at one rate of 10 t d.m. ha^{-1} (Fig. 3).

Likewise in our experiment, Wójtowicz and Jajor [Wójtowicz and Jajor 2006], who tested five oilseed rape cultivars, did not find any interaction between nitrogen fertilization or other agronomic factors and the composition of fatty acids. Spasibionek [Spasibionek 2002] also concluded that induced metagenesis was far more important for modification of fatty acids in oil crops.

CONCLUSIONS

1. Fertilization significantly modifies the content of crude fat in winter oilseed rape seeds, although the response of particular cultivars can be varied. The lowest amounts of fat are accumulated in seed of rape plants fertilized with manure and slurry in nitrogen balanced rates, and by sewage sludge-based fertilizers applied in a single rate of 10 t d.m. ha^{-1}.
2. The volume of crude oil yield depends primarily on seed yield obtained from oilseed rape. FYM fertilization as well as application of composts produced from sewage sludge makes it possible to obtain on average 2.5 t of fat per hectare.
3. The composition of fatty acids in oil produced from rape seeds depends mainly on cultivars. Mineral fertilization, application of high rates of slurry and single treatment

with sewage sludge increases the ratio of saturated acids in crude oil. In contrast, farmyard manure and double application of smaller rates of sewage sludge in a rotation system increase the share of mono- and poly-unsaturated fatty acids.

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