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THE EFFECT OF ORGANIC FERTILISATION OF LIQUID MANURE AND THE PRP FIX PREPARATION ON THE YIELD AND CHEMICAL COMPOSITION OF WINTER RAPE SEEDS AND SPRING WHEAT GRAIN

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ABSTRACT
In 2011–2013, a field experiment was carried out at the Experimental Station of Cultivar Evaluation in Szczecin-Dąbie. The experiment aimed at determining the effect of slurry without and with addition of increasing PRP Fix preparation doses on the crop yields and some of their qualitative traits. The soil where the experiment was set up was slightly acidic (pH_{KCL} 5.95); nitrogen, phosphorus and potassium contents were 0.86, 1.55 and 2.70 g·kg^{-1} d.m., respectively. The total content of macro-elements for this type of soil was average. The content of bioavailable forms of phosphorus, magnesium and sulphur was average, while that of potassium was high. The content of organic carbon in soil was low, while the C:N ratio was 10.2:1 and was average for that type of soils. The obtained results show that the applied fertilisation with slurry combined with PRP Fix preparation and PK fertilisation increased the yield of winter rape seeds and spring wheat grain and the content of macro-elements being examined in them. The yields of the test plants were larger in the fertilisation objects where fertilisation with slurry with addition of 8 kg PRP Fix preparation per 1 m^3 slurry was applied, when compared to those where only mineral fertilisation or slurry was used. Winter rape seeds and spring wheat grain usually contained more nitrogen, phosphorus, potassium, magnesium, calcium and sulphur in the fertilisation objects being fertilised with slurry with PRP Fix preparation in the amount of 8 or 12 kg per 1 m^3 slurry with additional PK fertilisation (experimental series II) compared to experimental series I without additional PK fertilisation. Differences in the content of macro-elements in test plants after application of the fertilisation scheme being used varied. These differences were not always significant.

Keywords: slurry, PRP Fix, crops, content of macro-elements, rape seeds, wheat grain

INTRODUCTION

Over the last dozen or so years, the production of natural fertilisers in Poland has decreased, as well as the range of mineral fertilisers has changed and their prices have increased very clearly. As a result of these circumstances, the doses of natural and mineral fertilisers per unit area have been reduced. This may lead to a reduction in soil fertility and productivity. These arguments have contributed to searching for new, moderately cheap and environmentally sound sources of organic matter and nutrients for plants [Krzywy 2005, Możdżer and Krzywy 2014].

At present, there are large amounts of slurry produced, the chemical composition of which indicates the possibility of using it for fertilisation purposes.

The use by plants is high because most of the nutrient is present in the form of the mineral, eg. nitrogen derived from slurry is better used by plants than from manure [Schepers and et al.

2008]. According to applicable legislation, slurry cannot be introduced into soil from early November to late February [Journal of Laws, 2008, No. 119, item 765].

Therefore, farms should be equipped with tanks of adequate capacity to store it at that time. Improper storage and use of slurry in spring, summer and autumn may result in environmental pollution (air, soil and water) and contribute to a reduction in plant crop quality. Properly stored slurry with simultaneous recovery of biogas has broad economic and ecological benefits, which inlude a reduction of odors [Nettmann and et. 2010].

According to the date presented by a French company Procedes Roland Pigeon, PRP Fix preparation being produced by it reduces odour emissions to atmosphere by 30% (including NH_3, H_2S and CH_4), increases the manurial value of animal dung, stimulates development of aerobic microorganisms in soils which decompose organic matter, and positively affects the environment.

Taking the above data into account, the study was undertaken which aimed at determining the effect of slurry with addition of increasing PRP Fix preparation doses on winter rape and spring wheat yields and some of their qualitative traits.

MATERIAL AND RESEARCH METHODS

A field vegetation experiment was carried out at the Experimental Station of Cultivar Evaluation in Szczecin-Dąbie in 2011–2013. The experiment aimed at determining the effect of slurry without and with addition of increasing PRP Fix preparation doses on the crop yield and qualitative traits and soil fertility indicators.

The Experimental Station of Cultivar Evaluation in Szczecin-Dąbie is situated in the south-eastern part of the city of Szczecin. The land of the ESCE in Szczecin-Dąbie belongs to very good, good and poor rye complexes of agricultural suitability, and IV[a] to VI soil quality classes. The experimental soil was characterised by slightly acidic reaction (pH_{KCL} 5.95); total nitrogen, phosphorus and potassium contents were 0.86, 1.55 and 2.70 $g \cdot kg^{-1}$ d.m., respectively. The total content of macro-elements for this type of soil was average. The content of bioavailable forms of phosphorus, magnesium and sulphur was average (55.3, 49.3 and 11.0 $mg \cdot kg^{-1}$ d.m., respectively), while that of potassium was high (132 $mg \cdot kg^{-1}$ d.m.). The content of organic carbon in soil was low (8.80 $g \cdot kg^{-1}$ d.m), while the C:N ratio was 10.2:1 and was average for that type of soils.

In early autumn 2011, a two-factor field experiment was set up according to a design presented in Table 1. The dose of slurry introduced into soil in experimental series I and II was determined based on its nitrogen content which corresponded to 100 kg $N \cdot ha^{-1}$.

Slurry without and with increasing doses of PRP Fix preparation was introduced on experimental plots on the following dates – on 19.08.2011 for winter rape and on 09.04.2013 for spring wheat.

Three days after slurry input to soil, mineral fertilisation was applied according to the study design. Table 1 presents the fertilisation scheme of the experiment being carried out. In spring 2012 and 2013, top dressing with nitrogen in the form of urea (46% N), at a dose of 45 kg $N \cdot ha^{-1}$ for winter rape and 30 kg $N \cdot ha^{-1}$ for spring wheat each, was applied on all fertilisation objects of experiment series I and II.

In experimental series II, based on phosphorus and potassium contents in slurry, additional mineral fertilisation was determined which amounted to 90 kg $P_2O_5 \cdot ha^{-1}$ in the form of granular triple super phosphate, containing 46% P_2O_5, which corresponded to a dose of 0.65 kg per plot and 100 kg $K_2O \cdot ha^{-1}$ in the form of potassium chloride (KCl), containing 60% K_2O, which corresponded to a dose of 0.55 kg KCl. Test plants was winter rape, cultivar *PR 46 W14*, in 2011–2012, and spring wheat, cultivar *Bombona*, in 2013.

Table 1. Testing diagram

Fertilisation objects	Series I	Series II
	without additional mineral fertilisation	with additional PK fertilisation
Mineral fertilisers corresponding to a slurry dose	+	+
Slurry without PRP Fix	+	+
Slurry + 4 kg of PRP Fix	+	+
Slurry + 8 kg of PRP Fix	+	+
Slurry + 12 kg of PRP Fix	+	+

After agro-technical treatments and application of fertilisers, winter rape seeds, cultivar *PR 46 W14*, were sown on 26.08.2011, and spring wheat grain, cultivar *Bombona,* on 16.04.2013. Winter rape was harvested on 25.07.2012, while spring wheat on 22.08.2013.

Each year, after reaching production maturity by test plants, they were harvested and crop yield was determined in $Mg \cdot ha^{-1}$. From each replications for a given fertilisation object, a sample of winter rape seeds and spring wheat grain was collected. An average sample was prepared which were subjected to laboratory examination. Spring wheat and winter rape straws were not sampled for examination because they were left on experimental plots as a source of organic matter for soil.

The samples of winter rape seeds and spring wheat grain were dried and ground. Thereafter, they were combined, forming average samples from four replications for each fertilisation object. The average samples of test plants were subjected to chemical analyses in three replications. In the plant material, dry matter was determined by oven-dry method at 105^0C, nitrogen by Kjeldahl distillation method after mineralisation in concentrated sulphuric(VI) acid – PN-75/A-04018/Az 3, phosphorus by the method of Burton, potassium and calcium by flame spectrophotometry after wet mineralisation, total sulphur by nephelometric method, magnesium by atomic absorption spectrometry (AAS) – PN-EN ISO 11212 and PN-EN ISO 11212–4 after wet mineralisation in the mixture of nitric(V) acid and chloric(VII) acid in a 3:1 ratio.

The yield of winter rape seeds and spring wheat grain and the content of macro-elements were analysed statistically. Two-factor analysis of variance for the split-block design was used in statistical calculations. Confidence semi-intervals were determined for $p = 0.05$, using the Tuckey's test.

RESULTS AND DISCUSSION

When analysing the yield of winter rape seeds obtained in 2012, it was shown that its highest yields in experimental series I without additional mineral fertilisation were observed in the fertilisation object with slurry without addition of PRP Fix preparation (fertilisation object 2) and next in that with slurry with 8 kg PRP Fix preparation per 1 m^3 slurry (fertilisation object 4). These yields were significantly higher compared to those from other fertilisation objects. The significantly lowest yield of winter rape seeds was obtained after application of slurry with addition of 12 kg PRP Fix per 1 m^3 slurry (Table 2). Additional mineral fertilisation in experimental series II (PK fertilisation) increased the yield of winter rape seeds by 7.60% compared to experimental series I without these fertilisers. In this experimental series, the highest yield of winter seed seeds was obtained after application of slurry with addition of 8 kg PRP Fix preparation per 1 m^3 slurry (fertilisation object 9). This yield was significantly higher compared to those from other fertilisation objects.

The highest yield of spring wheat grain (in 2013) was obtained after application of slurry with addition of 4 kg PRP Fix preparation per 1 m^3 slurry (fertilisation object 8) in experimental series II. This yield was significantly higher compared to those of other fertilisation objects. A significantly lower yield of spring wheat grain was obtained after application of slurry in the fertilisation where 12 kg PRP Fix preparation per 1 m^3 slurry was introduced (fertilisation object 5) – Table 2. An addition of mineral fertilisers significantly increased the yield of its grain in all fertilisation objects. In experimental series II, where additional PK fertilisation was applied, the highest yields of spring wheat grain were obtained after application of slurry with addition of 4 kg PRP Fix preparation per 1 m^3 slurry (fertilisation object 8), while the least one after application of slurry with addition of 12 kg PRP Fix preparation per 1 m^3 slurry (fertilisation object 10). An increase in the yield of spring wheat grain between these objects was 11.2%. Differences in the yield of spring wheat grain between particular fertilisation objects were significant. An average increase in the yield of spring wheat grain between experimental series I and II amounted to 12.5%. On the other hand, the biggest difference in the yield of spring wheat grain was obtained between fertilisation objects 1 and 6 (17.7%). On average, more powerful effects in the yields of these test plants were obtained in experimental series II (with PK fertilisation) – Table 2.

Fertilisation with slurry with addition of PRP Fix preparation and combined application of PK fertilisers not only had a favourable effect on the yield of winter rape and spring wheat but also positively affected the quality of test plant seeds and grain. The yield-forming effect of biological [organic] fertilisation on cultivated plants has been

Table 2. The influence of the liquid manure and the PRP Fix preparation on crop volume of the winter rape seeds of PW 46 W 14 subspecies and spring wheat of Bombona subspecies in Mg·ha^{-1} obtained with influence of the liquid manure and the PRP Fix preparation

Exsperiment series	Fertilisation objects	Yares of study	
		2012	2013
		rape seeds	wheat grain
Without fertilisation PK Series I	1	4.47	6.20
	2	4.83	6.70
	3	4.70	7.00
	4	4.80	6.54
	5	4.26	6.00
	mean	**4.61**	**6.49**
With additional PK fertilisation Series II	6	4.93	7.30
	7	4.95	7.20
	8	5.00	7.84
	9	5.13	7.45
	10	4.80	6.70
	mean	**4.96**	**7.30**
LSD$_{0,05}$ for: I-dose PRP Fix II- with and without of PK interaction		 0.04 0.02 0.04	 0.07 0.03 0.07

*** Explanation of fertilisation objects** – experimental series I: 1 – mineral fertilisers corresponding to a slurry dose, 2 – slurry without PRP Fix, 3 – slurry + 4 kg PRP Fix, 4 – slurry + 8 kg PRP Fix, 5 – slurry + 12 kg PRP Fix; experimental series II: 6 – mineral fertilisers corresponding to a slurry dose with additional PK fertilisation, 7 – slurry without PRP Fix + PK, 8 – slurry+ 4 kg PRP Fix + PK, 9 – slurry + 8 kg PRP Fix + PK, 10 – slurry + 12 kg PRP Fix + PK.

confirmed by the studies conducted by Jamroz et al. [2004] and Łabętowicza et al. [2000]. The results of this study are also confirmed by the experiments of Kalembasy and Kuziemskiej [1993], Harasimowicz-Herman and Herman [2004].

CHEMICAL COMPOSITION OF TEST PLANTS

Literature data show that excessive content or deficiency of macro-elements in plants, obtained as a result of fertilisation, decreases the fodder and nutritional quality of crop yields [Ciećko and Harnisz 2002, Czyżyk and Strzelczyk 2008, Lipiński 2007, Mattsson 1999].

Table 4 presents average contents of macro-elements in winter rape seeds and spring wheat grain according to Panak [1995], whereas the recorded contents of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur in test plants obtained in 2012 and 2013 are compared in Tables 4, 5 and 6.

When comparing the results obtained in this study (Table 5 to 7) with the data from Table 3, it can be conclude that:

- contents of macro-elements in winter rape seeds were lower than the average values given in Table 3, whereas those in spring wheat grain were higher (Table 4 to 6),
- magnesium, calcium and sulphur contents in winter rape seeds were lower, whereas nitrogen, phosphorus and potassium ones were larger (Table 4 and 5) compared to the average values given in Table 3,
- spring wheat grain contained more nitrogen and potassium (except fertilisation objects 1, 2 and 3) and less phosphorus and calcium (except fertilisation objects 9 and 10) and magnesium compared to the average values given in Tables 3 and 6.

The content of potassium and magnesium in winter rape seeds and spring wheat grain was within average content range with an upward trend, that of calcium in winter rape seeds was lower than the average value, and sulphur content in spring wheat grain was within average content range or slightly higher only in fertilisation objects with addition of PK fertilisation (experimental series II), whereas in winter rape seeds was lower.

Table 3. Average nitrogen, phosphorus, potassium, calcium, magnesium and sulphur contents in winter rape seeds and spring wheat grain in g·kg^{-1} d.m. [Panak 1995]

Plant	nitrogen	phosphorus	potassium	calcium	magnesium	sulphur
Rape	37.0	6.00	7.50	3.90	2.20	13.8
Wheat	21.2	4.40	3.60	1.30	1.70	1.50

Table 4. Content of nitrogen and phosphorus in the winter rape seeds and spring wheat grain obtained due to influence of the liquid manure and PRP Fix preparation

Exsperiment series	Fertilisation objects	nitrogen		phosphorus	
		total content in g·kg^{-1}d.m.			
		winter rape	wheat grain	winter rape	wheat grain
Without fertilisation PK Series I	1	28.2	22.1	6.07	3.29
	2	28.1	22.2	6.16	3.35
	3	27.8	22.5	6.24	3.41
	4	28.6	22.9	6.45	3.62
	5	28.0	23.2	6.35	3.58
	mean	**26.8**	**22.6**	**6.25**	**3.45**
With additional PK fertilisation Series II	6	28.9	22.3	7.06	3.41
	7	29.3	22.5	7.08	3.42
	8	28.4	23.0	7.10	3.50
	9	29.4	23.3	7.15	3.58
	10	28.5	23.0	7.10	3.60
	mean	**28.7**	**22.8**	**7.10**	**3.53**
LSD $_{0,05}$ for:					
I-dose PRP Fix		0.33	0.18	0.29	0.03
II- with and without of PK		0.14	0.08	0.13	n.s.
interaction		0.31	0.17	0.28	0.03

* Explanation of fertilisation objects is given under Table 2.

Table 5. Content of phosphorus and calcium in the winter rape seeds and spring wheat grain obtained due to influence of the liquid manure and PRP Fix preparation

Exsperiment series	Fertilisation objects	phosphorus		calcium	
		total content in g·kg^{-1}d.m.			
		winter rape	wheat grain	winter rape	wheat grain
Without fertilisation PK Series I	1	7.50	3.50	2.92	1.05
	2	7.90	3.52	2.94	1.10
	3	7.20	3.58	2.98	1.15
	4	7.80	3.74	3.35	1.26
	5	7.65	3.66	3.05	1.20
	mean	**9.11**	**3.60**	**3.09**	**1.15**
With additional PK fertilisation Series II	6	8.13	4.00	2.92	1.12
	7	8.15	4.06	2.96	1.19
	8	8.28	4.14	3.12	1.28
	9	8.40	4.27	3.30	1.48
	10	8.30	4.18	3.24	1.40
	mean	**8.25**	**4.13**	**3.11**	**1.29**
LSD $_{0,05}$ for:					
I-dose PRP Fix		0.18	0.07	0.04	n.s.
II- with and without of PK		0.08	n.s.	0.09	0.08
interaction		0.17	0.08	0.08	n.s.

* Explanation of fertilisation objects is given under Table 2.

Table 6. Content of magnesium and sulphur in the winter rape seeds and spring wheat grain obtained due to influence of the liquid manure and PRP Fix preparation

Exsperiment series	Fertilisation objects	magnesium		sulphur	
		total content in g·kg^{-1}d.m.			
		winter rape	wheat grain	winter rape	wheat grain
Without fertilisation PK Series I	1	2.12	1.10	12.0	1.35
	2	2.17	1.15	12.3	1.48
	3	2.14	1.21	12.5	1.55
	4	2.16	1.28	12.7	1.60
	5	2.15	1.25	12.7	1.57
	mean	**2.13**	**1.20**	**12.4**	**1.51**
With additional PK fertilisation Series II	6	2.17	1.12	12.1	1.41
	7	2.18	1.15	12.3	1.52
	8	2.23	1.25	12.5	1.59
	9	2.24	1.38	12.6	1.69
	10	2.22	1.30	12.7	1.65
	mean	**2.20**	**1.23**	**12.4**	**1.57**
LSD$_{0,05}$ for: I-dose PRP Fix II- with and without of PK interaction		0.04 n.s. 0.04	0.09 n.s. n.s.	0.12 n.s. n.s.	0.16 n.s. n.s.

* Explanation of fertilisation objects is given under Table 2.

When analysing the effect of slurry with PRP Fix preparation in the amount of 8 kg per 1 m^3 slurry, both in experimental series I and II, an increase was observed in nitrogen content in winter rape seeds and spring wheat grain between fertilisation objects 4 and 9, by 2.79% and 1.75%, respectively (Tab. 4). The highest increase in nitrogen content in winter rape seeds was obtained between fertilisation object 2 (slurry without PRP Fix) and fertilisation object 9 (slurry + 8 kg PRP Fix + PK), by 4.62%, whereas in spring wheat grain between fertilisation objects 1 and 9, by 5.43%. The results of this study show that PK fertilisation applied with PRP Fix preparation in experimental series II contributed to an increase in nitrogen content in winter rape seeds by 7.10% compared to experimental series I. On the other hand, an increase in nitrogen content in spring wheat grain between experimental series I and II was slight (Table 4).

The highest increase in phosphorus content was obtained in winter rape seeds between fertilisation object 1 and fertilisation object 9, by 17.8%, whereas in spring wheat grain between fertilisation objects 1 and 10, by 9.42% (Table 4). When comparing experimental series I with experimental series II, it can be conclude that additional PK fertilisation with PRP Fix preparation induced an increase in phosphorus content in winter rape seeds and spring wheat grain by 13.6% and 2.32%, respectively.

In the fertilisation objects with slurry combined with PRP Fix preparation in experimental series I and II (fertilisation objects 3, 4, 5, 8, 9 and 10), potassium content in test plants increased compared to fertilisation object 1 (Table 5). The application of slurry with addition of PRP Fix in the amount of 8 kg per 1 m^3 slurry in experimental series I and II contributed to an increase in potassium content in winter rape seeds and spring wheat grain between fertilisation object 4 and fertilisation object 9 by 7.69% and 14.2%, respectively. The highest increase in the content of chemical element being discussed was observed in test plants between fertilisation objects 1 and 9, by 12.0% and 22.0%, respectively. On the other hand, the lowest potassium level was obtained in the fertilisation object where only mineral fertilisation was applied corresponding to a slurry dose introduced into soil (fertilisation object 1). Summing up, it can be concluded that there was an average drop in potassium content in winter rape seeds and spring wheat grain between experimental series I and II, by 9.44% and 12.8%, respectively.

Slurry with PRP Fix preparation in the amount of 12 kg per 1 m^3 slurry in experimental series I and II induced an increase n calcium content in winter rape seeds between fertilisation objects 5 and 10, by 6.22% (Table 5). The highest increase in the content of chemical element under discussion was observed both in winter rape seeds and

spring wheat grain between fertilisation objects 1 and 9, by 13% and 40.9%, respectively. An average increase in calcium content in spring wheat grain by 12.2% was observed between experimental series I and II.

The highest increase in magnesium content was obtained in winter rape seeds between fertilisation object 1 and fertilisation object 9, by 5.70%, whereas in spring wheat grain between by 25.4% (Table 6).When comparing experimental series I with experimental series II, it was found that additional PK fertilisation with PRP Fix preparation contributed to an increase in magnesium content in both test plants to a small extent (3.28% and 2.50%).

Slurry with PRP Fix preparation in the amount of 8 and 12 kg per 1 m^3 slurry in experimental series I and II induced and increase in sulphur content in spring wheat grain between fertilisation objects 4 and 9 and fertilisation objects 5 and 10, by 5.62 and 5.1%, respectively (Tab. 6). On the other hand, when analysing the content of sulphur in winter rape seeds, there was an increase in it at almost the same level in fertilisation objects 4, 5, 9 and 10 compared to fertilisation object 1. It was found that an average increase in sulphur content occurred in spring wheat grain between experimental series I and II, by 3.97%, whereas its increase in winter rape seeds remained at the same level of 12.4 $g \cdot kg^{-1}$ d.m.

Both in experimental series I and II, without and with additional PK fertilisation, the highest content of macro-elements (nitrogen, phosphorus, potassium calcium, magnesium and sulphur) was observed in test plants from the fertilisation object where slurry with addition of 8 kg PRP Fix preparation per 1 m^3 slurry was applied. The lowest level of macro-elements being discussed was observed in fertilisation object 1 (only mineral fertilisation corresponding to a slurry dose being introduced into soil). Differences in the content of macro-elements in test plants after application of the fertilisation scheme being used varied. These differences were not always significant.

Taking into account the findings of Korzeniowska and Stanisławska-Glubiak [2007], Mazur and Maćkowiak [1998], Krzywy [2005], Kutera [2004] and Maćkowiak [2000], as well as Mercik et al. [2003], which characterise the indicators of crop yield quality depending on the content of micro-elements in plants, it can be concluded that supplementary phosphorus and potassium fertilisation with increasing PRP Fix preparation doses had no negative effect on the quality of harvested test plant yields.

CONCLUSIONS

1. The applied fertilisation with slurry combined with PRP Fix preparation and PK fertilisation increased the yields of test plants (winter rape seeds and spring wheat grain) and the content of macro-elements in them (nitrogen, phosphorus, potassium calcium, magnesium and sulphur).
2. The yields of test plants were larger in the fertilisation objects where fertilisation with slurry with addition of 8 kg PRP Fix preparation per 1 m^3 slurry was applied compared to those where only mineral fertilisation or slurry was used (fertilisation objects 1 and 2).
3. Test plants usually contained more nitrogen, phosphorus, potassium, magnesium, calcium and sulphur in the fertilisation objects being fertilised with slurry with PRP Fix preparation in the amount of 8 or 12 kg per 1 m^3 slurry with additional PK fertilisation (experimental series II) than in experimental series I without additional PK fertilisation.
4. The applied fertilisation scheme had no significant effect on an increase in sulphur content in winter rape seeds between experimental series I and II.
5. The yields of test plants and the content of macro-elements in them depended to a large extent on the content of macro-elements in slurry and mineral fertilisers (additional PK fertilisation – experimental series II).

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