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Fertiliser from sewage sludge ash instead of conventional phosphorus fertilisers?

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ABSTRACT

Jastrzębska M., Kostrzewska M., Treder K., Makowski P., Saeid A., Jastrzębski W., Okorski A. (2018): Fertiliser from sewage sludge ash instead of conventional phosphorus fertilisers? Plant Soil Environ., 64: 504–511.

Recycling of phosphorus (P) from municipal waste for the use as a fertiliser can be an alternative to the non-renewable resources of this element as well as a method in the management of civilisation by-products that are a burden to the environment. An innovative phosphorus suspension fertiliser, produced on the basis of ash from incineration of sewage sludge and phosphorus solubilising bacteria *Bacillus megaterium* was compared in field trials with spring wheat conducted in 2014 and 2015 with superphosphate and phosphorite. The new fertiliser was not inferior to the commercial fertilisers in terms of the effect on wheat yield volumes, the uptake of P by wheat and the sanitary condition of the wheat field, especially when grown protected from weeds, pathogens and pests. It is expected that such a fertiliser can be an alternative to fertilisers produced from non-renewable resources, provided it does not deteriorate the quality of agricultural production and will be safe for the environment.

Keywords: secondary raw material; agronomic evaluation; yield components; fungal diseases; phosphorus content

Production of fertilisers from secondary raw materials can be seen as a response to the European strategy of sustainable phosphorus (P) use (Schröder et al. 2010). Large fertilising potential regarding P can be attributed to ash derived from incineration of municipal sewage sludge (SSA). The P concentration in ash dry matter ranged from < 10% to < 20% (Smol et al. 2016). Incineration of sewage sludge eliminates harmful pathogens as well as organic and inorganic contaminants (Severin et al. 2014). The problem that still awaits a solution is how to tackle a possible presence of toxic metals in ash, but the latest technologies for production of fertilisers from such ash strive to reduce the content of toxic metals down to a safe level (Lekfeldt et al. 2016). Availability and uptake of P from the soil is influenced by many factors including P-solubility and soil conditions (Lazarević et al. 2018). Phosphorus compounds in unprocessed SSA are generally weakly soluble (Severin et al. 2014), which may restrain the effectiveness of a fertiliser produced from the ash. However, it can be improved when phosphorus solubilising microorganisms (PSM) are introduced

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to the formulation of a fertiliser. PSM are abundant in arable soils and transform P compounds that are hardly accessible to plants to bioavailable forms (Mohammadi 2012). PSM have also been used to raise the effectiveness of fertilisers produced from phosphorite rocks (Galavi et al. 2011). *Bacillus megaterium* is mentioned among the most efficient PSM (Mohammadi 2012). Wyciszkiewicz et al. (2016) demonstrated that these bacteria can effectively solubilise P from low quality raw materials. This finding is fundamental to the production of an innovative fertiliser made from SSA, with added bacteria *Bacillus megaterium*. The properties of this fertiliser were tested in field experiments, where they were confronted with traditional P fertilisers. This article presents an evaluation of the impact of the tested fertiliser on the productivity of wheat, P uptake by wheat plants, and infestation of wheat fields by weeds and pathogens. A research hypothesis was set forth, suggesting that the performance of a new fertiliser would not be inferior to that achieved by commercial fertilisers.

MATERIAL AND METHODS

Experimental design and agronomic management. Two field experiments were conducted at the Research and Production Farm Bałcyny Spółka z o.o. (Warmia and Mazury Province, Poland, 53.60°N, 19.85°E) in 2014 and 2015. The test plant was a spring cultivar of common wheat (*Triticum aestivum* ssp. *vulgare* MacKey).

A fertiliser produced from SSA (SSAB) was confronted with superphosphate Fosdar™ 40 (SP, 17.6% P) and phosphorite Syria (phosphate rock – PR, 12.2% P). SSA was obtained from the Łyna Municipal Wastewater Treatment Plant in Olsztyn (Poland), where it was generated by incineration of sewage sludge biomass, obtained from III° wastewater treatment. SSAB was produced at the Institute of New Chemical Syntheses in Puławy (Poland), according to a concept developed at the University of Science and Technology in Wrocław (Poland). This fertiliser is a product of microbiological decomposition of ash, comes in the form of a suspension and contains multiplied bacteria *Bacillus megaterium*. The procedure of obtaining fertiliser formulation was described elsewhere by Rolewicz et al. (2016). SSAB contains 0.176% mass P. Full elemental composition of used fertilisers was presented by Jastrzębska et al. (2016).

The compared treatments of fertilisation are given in Table 1. In 2014, the experiment was set up in a completely random design. SP and PR were applied in entire doses prior to sowing wheat. The SSAB total dose was split into 3 equal parts, which were applied on three dates: (1) before sowing – by large-drop sprinkling of the soil; (2) during the stage of wheat's three leaves and (3) in the early stem elongation phase, when the fertiliser was applied to soil between rows of wheat plants (to the depth of 5 cm). On (2) and (3) dates, suitably deep grooves were made between wheat rows with a wooden rod. The amount of suspension to be used on the particular date was divided into the number of grooves. The liquid was manually applied into each groove separately, using a plastic water bottle. An opening of appropriate size was made in the bottle cork and a relatively constant movement rate was maintained during the application to provide uniform distribution of fertiliser. Numerous blind pre-tests had been carried out elsewhere prior to the proper treatment. After application, the grooves were carefully strewed with soil using a hand rake. At one time, along with the appropriate P amount 0.4 L of solution per 1 m^2 of plot was applied.

Table 1. Fertilisation treatments tested in the experiments

Year	Treatment symbol	Fertiliser	Phosphorus dose (kg/ha)
2014*	control		0
	SP	superphosphate	21
	PR	phosphorite	21
	SSAB	fertiliser from ash	21
2015	control		0
	SP_1	superphosphate	17.6
	SP_2		26.4
	SP_3		35.2
	PR_1	phosphorite	17.6
	PR_2		26.4
	PR_3		35.2
	$SSAB_1$	fertiliser from ash	17.6
	$SSAB_2$		26.4
	$SSAB_3$		35.2

*The treatments belonged to a larger, preliminary research, the results of which have been partly published (Jastrzębska et al. 2015, 2016)

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Table 2. Basic agricultural data for the experiments

Item		2014	2015
Cultivar		Trappe	Monsun
Previous crop		spring barley	cereal-legume mixture
Soil tillage system		plough tillage	
Fertilisation	N (kg/ha) (ammonium sulphate)	100 (50* + 50**)	110 (60* + 50**)
	K (kg/ha) (potassium chloride)	99.6*	83*
Plant protection		– PP	–PP or +PP
	herbicides		MCPA (19 May)
	fungicides		azoxystrobin + propiconazole (11 June) cyproconazole (11 June)
	insecticides		lambda-cyhalothrin (10 June)
Sowing date		25 April	9 April
Harvest date		11 August	11 August

*pre-sowing; **at wheat stem elongation; –PP – no plant protection; +PP – complete plant protection

This application method was chosen to observe the adaptation process of *Bacillus megaterium* in soil. The plants were not protected against weeds, pathogens or pests. In 2015, the experiment was expanded by adding plant protection as a factor: +PP – complete plant protection; –PP – no plant protection. The experiment was set up in a parallel strip design. The P fertilisers were applied once, prior to wheat sowing: SP and PR were applied manually (scattered) on the soil surface while the SSAB was applied by large-drop sprinkling of the soil. Along with particular P doses at SSAB the amount of solution representing 1.0, 1.5, and 2.0 L/m^2 was applied, respectively. The fertilisers were mixed with the soil by harrowing. All the other elements of the applied agricultural technology were made uniform in the individual years (Table 2). In both experiments, experimental treatments were performed in 4 replications (plots). The size of a single experimental plot was 20 m^2.

Soil and meteorological conditions. Wheat was grown on soil that responded well to wheat nutritional requirements (Table 3). In both plant growing seasons the weather was drier than the long-term average (Table 4). In 2014, the drought in May fell exactly on the period of plant emergence. Later, the shortage of rainfall in July accelerated plant ripening. In 2015, drought occurred during the tillering and stem elongation phases (May, June). The temperature and moisture conditions in July were favourable for the grain filling, while the scanty rainfall and high temperatures in early August did not harm the plants.

Plant sampling. The yield volume evaluation was based on the quantity of grain harvested from particular plots. The results were transformed per 1 ha. The wheat yield structure parameters were determined: spike density per 1 m^2 – measured with the frame method prior to wheat harvest, number of grains per spike – based on measurements on 25 plants sampled from each plot, and 1000 grain weight (TGW) – based on grain samples collected during the harvest. Weed density and aboveground biomass per 1 m^2 were determined at wheat maturity. At the same stage the degree of wheat infestation by fungal pathogens was estimated. 25 plants from each plot were submitted to analyses. The incidence of stem base diseases was assessed on the Ponchet's scale modified by Mackiewicz and Drath (1972), while the presence of diseases affect-

Table 3. Soil characteristics before the start of the experiments

Property		2014	2015
Soil type*		Luvisols	Luvisols
Soil texture		sandy clay loam	sandy loam
pH_{KCl}		6.23	5.32
Total**	C (g/kg)	8.31	8.90
	N (g/kg)	1.30	1.35
	P (mg/kg)	574	566
	K (mg/kg)	2979	2895
	Mg (mg/kg)	2070	2007

*according to FAO (2014); **measured with the Inductively Coupled Plasma-Optical Emission Spectrometry technique

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Table 4. Precipitation and air temperature during the period of study according to the Meteorological Station in Bałcyny (Poland)

Month	Precipitation (mm)			Air temperature (°C)		
	2014	2015	1981–2010	2014	2015	1981–2010
April	26.1	23.4	29.8	9.5	7.2	7.7
May	34.9	25.4	62.3	13.3	12.1	13.2
June	72.2	43.0	72.9	14.8	15.7	15.8
July	20.4	71.0	81.2	21.0	18.0	18.3
August	59.2	13.0	70.6	17.9	21.3	17.7
Total/average for April–August	212.8	175.8	316.8	15.3	14.8	14.5

ing leaves and spikes was analysed on the scale by Hinfner and Papp (1964). Disease intensity was presented as an infestation index by McKinney (1923).
Chemical analysis. The appropriate mass (0.5 g) of plant samples was digested in Teflon vessels (microwave oven Milestone MLS-1200, Sorisole, Bergamo, Italy) with 5 mL of concentrated 65 mg/kg HNO_3 suprapur grade from Merck. After mineralisation, all samples were diluted to 50 mL. The ICP-OES with an pneumatic nebulizer with axial view (iCAP Duo Thermo Scientific, Waltham, USA) was used to measure the concentration of P in so prepared samples.

Statistical analysis. The results were submitted to one- and two-factorial analysis of variance or, alternatively, the Kruskal-Wallis non-parametric test if the analysis of variance assumptions were not met. The normality of variable distribution was checked using the Shapiro-Wilk W-test and the homogeneity of variance – using the Levene's test. The differences between objects were evaluated using the Duncan's test or a multiple comparison test. The relationship between grain yield and yield structure elements as well as the dependence of P uptake on the yield volume and P content in grain and straw were determined with simple correlation coefficients. The calculations were supported by Statistica software (StatSoft, Inc. 2014). The tables and figures present average values from 4 plots.

RESULTS AND DISCUSSION

Grain yield. In both experiments, spring wheat responded to P fertilisation by producing higher yields (Table 5). In 2014, the yield of wheat fertilised with SSAB did not differ from the yields obtained using the commercial fertilisers. In 2015, the yield-promoting effect of $SSAB_{1,2,3}$ was comparable to that of $PR_{1,2,3}$ and SP_1. In turn, the increasing doses of P introduced to soil with SP gradually raised the wheat grain yield. No yield stimulating effects of increasing P doses applied

Table 5. Grain yield and yield structure elements of spring wheat

Year	Treatment	Grain yield (t/ha)	Spike density (No./m^2)	Grains per spike (No.)	TGW (g)
2014	control	4.18^b	557^a	31.8^b	32.1^b
	SP	5.40^a	609^a	35.6^a	34.4^a
	PR	4.77^{ab}	634^a	34.3^{ab}	33.4^{ab}
	SSAB	5.26^a	593^a	36.7^a	34.3^a
	r		ns	0.807	0.858
2015	control	4.85^d	466^a	22.5^a	51.6^b
	SP_1	5.42^{bc}	484^a	23.5^a	52.9^{ab}
	SP_2	5.60^{ab}	480^a	24.5^a	53.5^{ab}
	SP_3	5.83^a	497^a	24.5^a	54.3^a
	PR_1	5.43^{bc}	467^a	23.5^a	53.8^{ab}
	PR_2	5.49^{bc}	470^a	24.5^a	53.8^{ab}
	PR_3	5.52^{bc}	469^a	24.5^a	54.2^a
	$SSAB_1$	5.25^c	461^a	23.5^a	53.4^{ab}
	$SSAB_2$	5.50^{bc}	476^a	24.0^a	53.8^{ab}
	$SSAB_3$	5.29^c	493^a	22.5^a	53.5^{ab}
	–PP	4.73^b	454^b	23.0^b	52.3^b
	+PP	6.11^a	498^a	25.0^a	54.7^a
	r		0.548	0.757	0.770

$^{a–d}$Different letters indicate significant differences at $P = 0.05$; *r* – simple correlation coefficient (relationship between grain yield and yield structure elements); ns – not significant at $P = 0.05$. SP – superphosphate; PR – phosphorite; SSAB – fertiliser from ash; –PP – no plant protection; +PP – complete plant protection; TGW – 1000 grain weight

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with SSAB and PR were noted. On the other hand, the increasing P doses in the form of SP raised the wheat grain yield. Full plant protection increased the grain yield (by 29.2% on average).

When no plant protection was applied (–PP), grain yields of wheat fertilised with $SSAB_{1,2,3}$ did not differ from the control ones, nor did they diverge from those obtained under the effect of $PR_{1,2,3}$ or SP_1 (Figure 1a). Under the –PP conditions, SP_3 proved to be the most conducive to higher grain yields. Plants under +PP utilised the available P much better to form yields. An increase in yielding was noted both for plants using only the soil P resources and for those supplied with P fertilisers. Under +PP, the yield stimulating effect of $SSAB_{1,2,3}$ was on par with the impact of $SP_{1,2,3}$ and $PR_{1,2,3}$. Regardless of the applied fertiliser, the yield around 6 t/ha was already ensured by the lowest applied dose, and it was not justifiable to apply higher doses. Yield stimulating effects of fertilisers from SSA were reported previously (Weigand et al. 2013, Severin et al. 2014), same as the role of PSM in the improved efficiency of P fertilisers (Galavi et al. 2011, Ram et al. 2015). However, more research is needed on the reasonability of incorporating PSM into fertilisers from waste. In our larger preliminary research (2014), SSAB slightly increased the yield of wheat as compared to the ash-water solution (without PSM), although the effect was not statistically significant (Jastrzębska et al. 2016). In further research, granular fertiliser from SSA and animal blood with *B. megaterium* showed the same or better efficiency than an analogue treatment without bacteria (own data, unpublished). The weak response of wheat to the PSM addition and to the increase in P doses noted in the current study may have been a consequence of the P richness of the soil (Ram et al. 2015, Mühlbachová et al. 2017).

Yield structure components. SSAB, same as SP and PR, had no effect on the density of wheat spikes in 2014 and 2015, nor did it affect the number of grains per spike in 2015 (Table 5). In 2014, SSAB raised the number of grains per spike compared to the control, thus producing an effect comparable to that of SP and PR. In both years, P fertilisation had a beneficial influence on TGW, and the effect of SSAB was similar to that of SP and PR. In 2015,

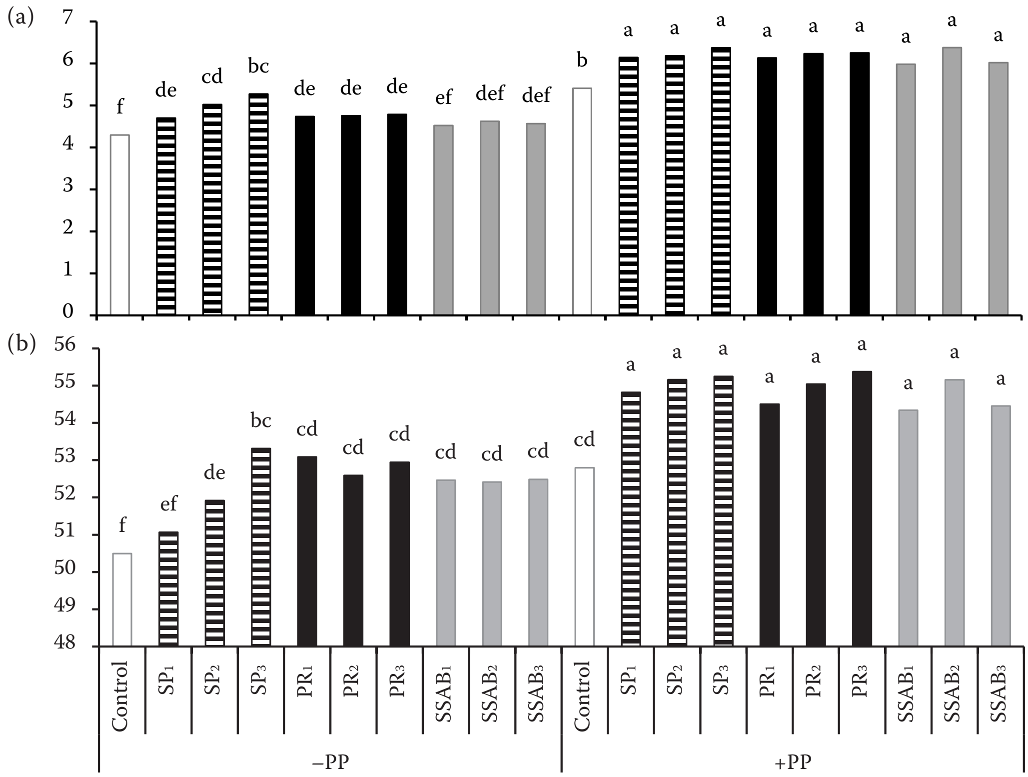

Figure 1. Influence of interaction between phosphorus (P)-fertilisation and plant protection on (a) spring wheat yield (t/ha) and (b) the weight of spring wheat 1000 grains (g). $^{a–f}$Different letters indicate significant differences at P = 0.05. SP – superphosphate; PR – phosphorite; SSAB – fertiliser from ash; –PP – no plant protection; +PP – complete plant protection

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Table 6. Content of phosphorus (P) in grain and straw and total P uptake by wheat plants

Year	Treatment	Grain P (g/kg DM)	Straw P (g/kg DM)	Total uptake (kg/ha)
2014	control	3.60^{a}	0.50^{a}	20.1^{b}
	SP	3.59^{a}	0.46^{a}	24.6^{a}
	PR	3.56^{a}	0.45^{a}	21.7^{b}
	SSAB	3.73^{a}	0.48^{a}	25.1^{a}
2015	control	3.56^{a}	0.33^{a}	28.4^{b}
	SP_1	3.43^{a}	0.32^{a}	30.4^{ab}
	SP_2	3.49^{a}	0.34^{a}	32.1^{a}
	SP_3	3.44^{a}	0.33^{a}	32.6^{a}
	PR_1	3.58^{a}	0.32^{a}	31.8^{a}
	PR_2	3.47^{a}	0.36^{a}	31.4^{a}
	PR_3	3.51^{a}	0.34^{a}	32.2^{a}
	$SSAB_1$	3.66^{a}	0.32^{a}	31.4^{a}
	$SSAB_2$	3.38^{a}	0.32^{a}	30.5^{ab}
	$SSAB_3$	3.52^{a}	0.32^{a}	30.3^{ab}
	–PP	3.39^{b}	0.35^{a}	26.4^{b}
	+PP	3.64^{a}	0.31^{b}	35.8^{a}

[a,b]Different letters indicate significant differences at P = 0.05; DM – dry matter. SP – superphosphate; PR – phosphorite; SSAB – fertiliser from ash; –PP – no plant protection; +PP – complete plant protection

irrespective of the fertiliser applied, an increase in the P dose above 17.6 kg/ha did not matter. Plant protection improved all yield components.

In 2015, under the –PP conditions, the effect of $SSAB_{1,2,3}$ on TGW was similar to that achieved by $PR_{1,2,3}$ as well as $SP_{2,3}$ while being more favourable than that of SP_1 (Figure 1b). In plants under +PP, P fertilisation, irrespective of the type of fertiliser and P dose, identically improved TGW. +PP alone made up for the lack of P fertilisation, increasing TGW to the level observed in plants fertilised with P but under –PP (with the exception of SP_1).

Table 7. Dependence of the phosphorus (P) uptake on yield volume and P content in grain and straw – simple correlation coefficients (r)

Year	Phosphorus		Yield	
	grain	straw	grain	straw
2014	ns	ns	0.894	0.549
2015	0.688	ns	0.896	0.642

ns – not significant at P = 0.05

The yield volume depended mostly on TGW, followed by the number of grains per spike and, finally, the density of spikes (Table 5). The literature lacks an unambiguous answer as to the contribution of yield structure components to cereal yields (Rymuza et al. 2012).

The content and uptake of P. The content of P in grain and straw was not determined by the type of fertiliser (2014, 2015) or a P dose (2015) (Table 6). However, +PP (2015) contributed to an increased P content in grain and a decreased one in straw. In 2014, the total P uptake by wheat plants (grain + straw) conditioned by SSAB equalled and surpassed, respectively, the P uptake as affected by the SP and PR. In 2015, the P uptake influenced by $SSAB_{1,2,3}$ did not differ from uptake observed under the influence of $SP_{1,2,3}$ and $PR_{1,2,3}$. In 2015, +PP considerably improved the P uptake by wheat plants. The total P uptake by wheat plants was strongly correlated with the grain yield (Table 7). The bioavailability of P from SSA tends to be evaluated as low (Severin et al. 2014), but can vary depending on the process of ash production and further processing (Lekfeldt

Table 8. Weed infestation of spring wheat before harvest

Year	Treatment	Density (No./m^2)	Biomass (g/m^2)
2014	control	104^{ab}	62.5^{ab}
	SP	106^{ab}	44.8^{ab}
	PR	147^{a}	76.8^{a}
	SSAB	70^{b}	22.6^{b}
2015	control	135^{a}	61.1^{a}
	SP_1	146^{a}	74.1^{a}
	SP_2	134^{a}	90.2^{a}
	SP_3	131^{a}	47.8^{a}
	PR_1	147^{a}	70.5^{a}
	PR_2	134^{a}	67.8^{a}
	PR_3	138^{a}	57.9^{a}
	$SSAB_1$	127^{a}	58.5^{a}
	$SSAB_2$	132^{a}	63.8^{a}
	$SSAB_3$	135^{a}	70.1^{a}
	–PP	209^{a}	117.4^{a}
	+PP	62^{b}	14.9^{b}

[a,b]Different letters indicate significant differences at P = 0.05. SP – superphosphate; PR – phosphorite; SSAB – fertiliser from ash; –PP – no plant protection; +PP – complete plant protection

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Table 9. Intensity of fungal diseases of spring wheat (infestation index Ip) (%)

Year	Treatment	Stem base		Leaf		Spike	
		Fusarium sp.	*Tapesia yallundae*	*Blumeria graminis*	*Septoria tritici*	*Stagonospora nodorum*	*Fusarium* sp.
2014	control	25.3[a]	3.0[a]	18.1[a]	7.0[a]	6.1[a]	0.0[a]
	SP	28.8[a]	0.0[b]	11.6[a]	13.0[a]	8.2[a]	2.8[a]
	PR	23.0[a]	1.0[b]	13.3[a]	11.3[a]	10.7[a]	3.0[a]
	SSAB	27.8[a]	0.0[b]	11.0[a]	10.8[a]	8.6[a]	2.7[a]
2015	control	31.3[a]	0.0[a]	23.9[a]	11.1[a]	25.3[a]	11.3[a]
	SP_1	42.5[a]	0.7[a]	23.0[a]	14.0[a]	29.7[a]	14.4[a]
	SP_2	31.3[a]	1.7[a]	24.6[a]	10.6[a]	22.7[a]	9.9[a]
	SP_3	32.3[a]	4.3[a]	21.5[a]	10.3[a]	22.0[a]	11.7[a]
	PR_1	26.8[a]	1.0[a]	21.5[a]	11.1[a]	29.3[a]	13.5[a]
	PR_2	29.5[a]	4.0[a]	19.9[a]	11.0[a]	24.7[a]	11.7[a]
	PR_3	33.5[a]	0.7[a]	21.7[a]	13.7[a]	32.3[a]	13.8[a]
	$SSAB_1$	30.8[a]	1.7[a]	21.8[a]	14.8[a]	28.3[a]	12.8[a]
	$SSAB_2$	37.3[a]	3.3[a]	24.3[a]	16.7[a]	29.7[a]	13.9[a]
	$SSAB_3$	36.3[a]	2.3[a]	22.6[a]	15.7[a]	31.7[a]	12.5[a]
	–PP	31.2[a]	2.7[a]	29.3[a]	10.9[b]	35.5[a]	7.4[b]
	+PP	35.1[a]	1.3[a]	15.6[b]	14.9[a]	19.6[b]	17.7[a]

[a,b]Different letters indicate significant differences at $P = 0.05$. SP – superphosphate; PR – phosphorite; SSAB – fertiliser from ash; –PP – no plant protection; +PP – complete plant protection

et al. 2016). Wyciszkiewicz et al. (2016) demonstrated that *Bacillus megaterium* bacteria were much more efficient at solubilising P from SSA than P derived from the PR. Lekfeldt et al. (2016) did not identify any significant effect of the tested bioeffectors (including *Bacillus*) on the growth of wheat aboveground biomass or on its uptake of P when the plants were nourished with fertilisers produced from recycled materials.

Weed infestation of wheat fields. In 2014, SSAB tended to reduce the weed infestation of wheat (Table 8). Compared with PR, which seemed to favour the development of weeds (it may be associated with an increased content of Ca in PR, Lundy et al. (2010)), the change in the density and biomass of weeds under the influence of SSAB was significant. These promising findings, however, were not supported in the second year. Moreover, no interactions were found between the tested fertilisers and plant protection.

Weed infestation of crop fields is still a rare subject in the area of research dedicated to the performance characteristics of fertilisers and biofertilisers, also ones based on renewable resources. Hussein and Samir (2001) did not observe changes in weed biomass in wheat fields following an inclusion of PSM and *Azospirillum* ssp. to traditional nitrogen and phosphorus fertilisation.

Fungal diseases. Although it is commonly believed that proper nutrition of plants with P lowers their susceptibility to fungal diseases (Grzebisz et al. 2003), no differences between the fertilisation objects were noted in this regard, except for the pathogen *Tapesia yallundae*, which in 2014 occurred almost exclusively on the control plots, while virtually causing no disease symptoms on P fertilised plants (Table 9). Eswaran and Manivannan (2007) mentioned that lignite fly ash application may induce resistance of plants to fungal diseases.

The applied fungicides (2015, +PP) did not have an effect on the intensity of stem base diseases, but reduced the rate of infection by *Blumeria graminis* and *Stagonospora nodorum*. In plants under +PP, the development of *Septoria tritici* and *Fusarium* sp. on spikes was more intensive. This can be explained by differences in the susceptibility of particular pathogens to the applied fungicides and by the changes the chemicals caused in the competitive structure between pathogenic strains (Karlsson et al. 2014). No in-

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teraction was noted between plant protection and fertilisation variants.

Recapitulating, the SSAB fertilising suspension was not less effective than the commercial fertilisers regarding its yield stimulating influence as well as the impact on P uptake and sanitary condition of wheat fields, especially those where agrophages were controlled. As expected, the above fertiliser can be an alternative to fertilisers with P from non-renewable resources, provided it does not deteriorate the quality of harvested products and is safe for the environment.

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