INFLUENCE OF DIFFERENT FERTILIZATION SYSTEMS AND LIMING ON POTATO TUBER YIELD AND YIELD STRUCTURE

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Abstract

The aim of the study has been to evaluate the influence of long-term application of three fertilization systems on the volume and structure of potato tuber yield. The first system was based on natural fertilizers, farmyard manure (FYM) and slurry, both from a swine farm; the second one included natural fertilizers supplemented by PK fertilizers in half the dose of these elements in the NPK treatment and the third one consisted exclusively of NPK mineral fertilizers. The control treatment was unfertilized. The experiment consists of two series, without liming and with liming under winter wheat preceding potato in the crop rotation. In the paper, the results obtained in the fifth rotation cycle are presented. Significantly increased tuber yield appeared under all fertilization systems. Slurry supplemented by PK fertilizers increased the yield of potato tubers in comparison to FYM alone or FYM with PK fertilizers. The highest yield was achieved in the treatment with slurry rate II (balanced in terms of the amount of organic carbon introduced to soil in farmyard manure), supplemented by PK fertilizers. Liming increased the tuber yield by 2.9 $Mg \cdot ha^{-1}$in all fertilization treatments except FYM+PK. On average, marketable tubers made up about 90% of the total potato yield. The highest yield of marketable tubers was found in the treatment with slurry rate I (balanced in terms of the amount of total N introduced to soil in farmyard manure)+PK. Liming had some effect on calcium accumulation in potato tubers and on the process of tuber formation, increasing the total number of tubers.

Key words: slurry, farmyard manure (FYM), potato yield, potato yield structure

Introduction

Over the last years, the share of cereal crops in Poland has been rising steadily, while that of tuber and root crops has been on the decline. As a result, cereals now make up about 70% of all grown crops, whereas the share of tuber and root crops equals *ca* 6% [Main Office of Statistics 2011]. The latter crops, however, help to maintain a constant level of humus in soil. Potato and sugar beet respond positively to natural and organic fertilizers. The recommended dose of manure under potato, i.e. 30 Mg ha^{-1}, covers a substantial part of the crop's nutrient requirements. Among the natural fertilizers used in potato cultivation, swine and cattle slurry are mentioned. Due to its high content of nitrogen and phosphorus, potentially harmful to the environment, slurry is listed in the Nitrates Directive [1991] as a fertilizer whick application must be regulated. The Nitrate Directive states that crops grown in the EU countries may be fertilized with slurry up to the amount which supplies 170 kg N ha^{-1} annually. When applying natural fertilizers, the farmer should pay attention to maintaining a proper balance of fertilizer rates, supplementing nutrient deficits with mineral fertilizers. According to Wierzejska-Bujakowska [1998], the N: P:K ratio in production of table potato should be 1.0:0.4:1.3. In slurry, this ratio is usually 1.0:0.3:0.8 [Nowacki et al. 2005], and therefore this natural fertilizer should be supplemented by additional amounts of phosphorus and potassium in the mineral form.

The yield and quality of potato tubers are most strongly affected by nitrogen. By having a profound impact on the growth of plants' green parts, responsible for photosynthesis, a good supply of nitrogen may lead to a high yield of tubers [Oliveira 2000]. However, the quality of tubers is worse when nitrogen is not adequately balanced with other nutrients [Sowa-Niedziałkowska 2000]. An excessive nitrogen supply delays the ripening of tubers, decreases the content of starch, protein, polyphenols, citric acid or vitamin C and increases the content of sugars, free amino acids and nitrates [Porter and Sisson 1993, Zebarth et al. 2004]. Another consequence is the diminished saturation of cell walls with lignin, which impairs the resistance of tubers to mechanical damage and increases their vulnerability to diseases. However, Chmura [2000] claims that an excess of nitrogen decreases the share of small tubers and increases the percentage of larger, marketable ones. According to Ozgen and Palta [2004], formation of tubers can be adversely affected by elevated nitrogen fertilization. High temperature has a similar, negative effect on tuber formation, while a short day photoperiod favours this process Ewing, Struik 1992, Jackson 1999, Ozgen, Palta 2004].

It has not been completely elucidated yet how environmental and agronomic factors influence potato tubers. Some authors suggest an important role of plant hormones, e.g. gibberellic acid (GA) in this process. A high level of GA in plant tissues inhibits this process, while less gibberellin improves tuber formation. It has been clearly demonstrated that the effect of GA is strictly connected with the level of intracellular calcium (cytosolic Ca). Calcium is responsible for the integrity of cell membranes and when present in the form of a complex with protein kinase, called calmodulin (calcium-modulated-protein), this element affects the growth and development of plants. Hence, it can also influence the process of tuber formation and consequently the structure of potato tuber yield [Jackson 1999].

The aim of this research was to determine the effect of different fertilization systems on the yield of potato tuber and the yield structure.

Material and methods

A permanent field experiment has been carried out at the Experimental Station Tomaszkowo near Olsztyn (53°42'35" N, 20°26'01" E) since 1973. The design of the experiment was developed by Professor Teofil Mazur, from the Department of Environmental Chemistry, UWM Olsztyn. The experiment was established on acid brown soil originating from loamy sand classified as good rye complex. In the World Reference Base for Soil Resources, this soil belongs to Cambisols-Brown Soils [FAO 2006]. The design of the experiment (Table 1) was as follows: A) control treatment, B) slurry rate I,balanced every year in terms of the amount of nitrogen added to soil in farmyard manure (F) and NPK (H), C) slurry rate I + ″PK introduced to the soil with NPK fertilization (H), D) slurry rate II, balanced in terms of the amount of organic carbon introduced to soil in farmyard manure (F),

Table 1. *Design of the experiment and amounts of nutrients supplied annually (means for 1973-2009)*

Treatments		N	P	K	Mg	Ca
		kg·ha^{-1}·year^{-1}				
A	Without fertilization	-	-	-	-	-
B	Slurry I rate	133	56	84	18	26
C	Slurry I rate+PK	133	77	147	18	26
D	Slurry II rate	393	168	240	50	77
E	Slurry II rate+PK	393	190	302	50	77
F	Farmyardmanure (FYM)	133	45	108	19	37
G	FYM+PK	133	66	170	19	37
H	NPK	133	43	124	-	-

E) slurry rate II +″ PK introduced to the soil with NPK fertilization (H), F) farmyard manure – a dose of N equal to the N introduced with slurry rate I (C) and NPK (H), G) farmyard manure + ″ PK introduced to the soil with NPK fertilization (H), H) mineral fertilizers NPK (every year, the PK dose was calculated according to the fertilizer needs of the plants). The experiment comprises two series, without liming and after a single liming treatment in 2006 (2.7 Mg ha^{-1} of chalk containing 55% $CaCO_3$).

The crops were initially grown in an eight-year and then in a seven-year crop rotation system. In the first rotation system, the following plants were grown: potato, spring barley + under sown clover with grasses, clover with grasses, winter oilseed rape, winter wheat + rye after crop, maize grown for silage, spring barley, winter wheat. The second and subsequent rotations did not comprise red clover with grasses. In the sixth rotation cycle, i.e. in 2009, the medium-early, edible potato cv. Cekin was grown.

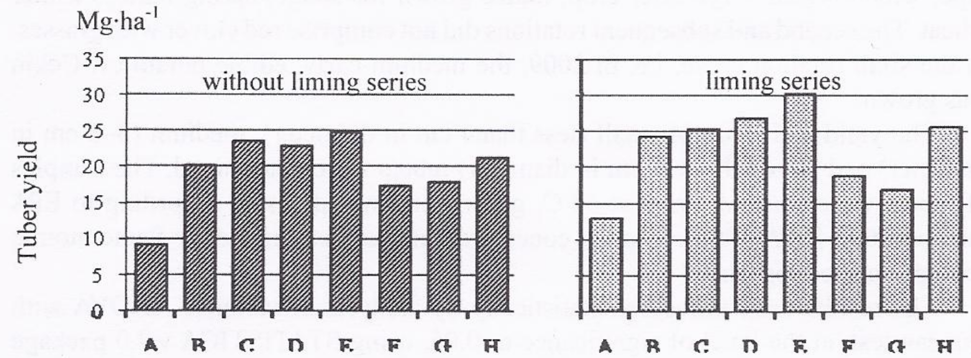
The yield and share of small (less than4 cm in diameter), medium (4–6 cm in diameter) and large (above 6 cm in diameter) tubers were determined. The samples of tubers were washed, dried at 65°C, ground and wet digested according to EPA method 3052 [EPA 1996]. The Ca concentration was determined by flame atomic absorption spectroscopy.

The results were processed statistically by analysis of variance ANOVA with Duncan test, at the level of significance α=0.05, using STATISTICA v.9.0 package [StatSoft 2009].

Results and Discussion

The potato cultivar Cekin, grown in this experiment, was entered into the Polish register of cultivars in 2004. The research carried out at the IHAR and COBORU has demonstrated that an average yield produced by this cultivar is 43.2 Mg ha^{-1} [Chotkowski, Stypa 2010].

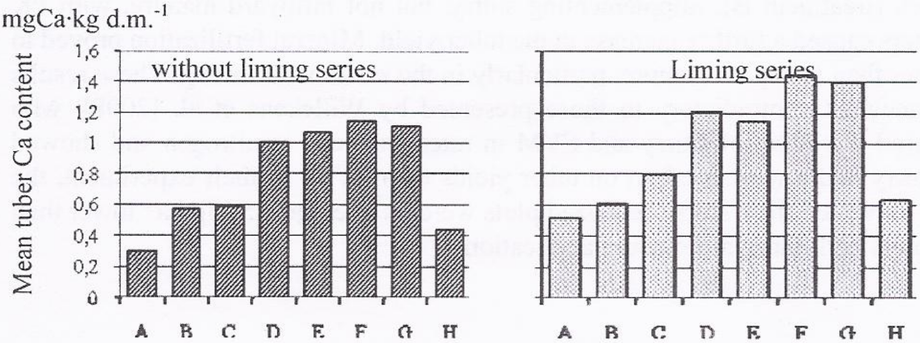
In the authors' own research, the highest tuber yield was 25 Mg·ha^{-1} in the unlimed series and 30 Mg·ha^{-1} in the series with liming (Fig. 1). Liming significantly increased the yield of tubers in all the fertilization treatments (on average by 2.9 Mg·ha^{-1}) except the treatment with farmyard manure supplemented with PK fertilizers (treatment G). Slurry gave higher increases of tuber yield than manure, on average by more than 5.26 Mg·ha^{-1}. Slurry applied in the rate balanced with FYM in carbon (treatment D) gave a better effect than in the rate balanced with FYM in nitrogen (treatment B). Supplementing slurry, but not farmyard manure, with PK fertilizers caused a further increase in the tuber yield. Mineral fertilization proved to be better than farmyard manure, particularly in the series with liming. These results are somewhat contradictory to those presented by Willekens et al. [2008], who compared the effect of slurry and FYM in rates balanced in nitrogen and showed that slurry had a weaker effect on tuber yields than FYM. In their experiment, the yields harvested from slurry-fertilized plots were on average 1.5 Mg·ha^{-1} lower than from plots with farmyard manure application.



A– without fertilization, B – slurry rate I, C – slurry rate I +PK, D – slurry rate II
E –slurry rate II +PK, F –FYM, G –FYM+PK, H – NPK
LSD $_{(\alpha=0.05)}$ for fertilization system 5.49, for liming 2.74, for interaction 7.77

Fig. 1. Effect of liming under different fertilization systems on the yield of potato tubers.

The fertilization systems had a significant influence on the content of calcium in tubers of the analyzed potato cultivar (Fig. 2). The lowest calcium concentration, 0.30 mg Ca kg^{-1}d.m., was determined in tubers from the control plot (treatment A). In the treatments with slurry rate I, slurry rate I supplemented with PK fertilizers (treatments B and C) and with

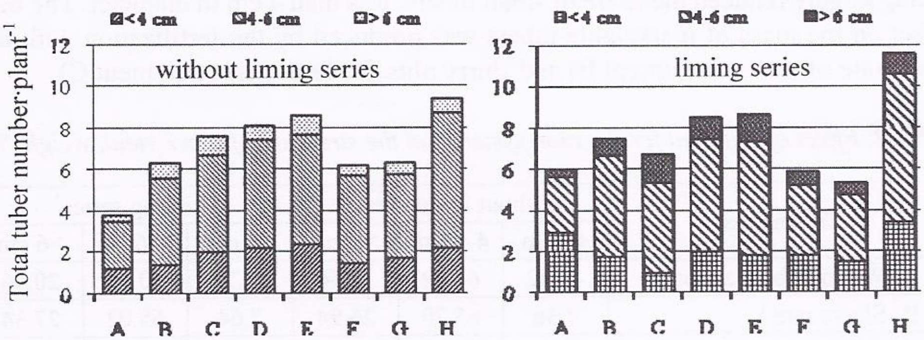


LSD $_{(\alpha=0.05)}$ for fertilization system 0.078, for liming 0.038, for interaction 0.110

Fig. 2. Effect of liming under different fertilization systems on the concentration of Ca in potato tubers.

mineral fertilizers only (treatment H), the concentration of Ca in tubers increased significantly. However, the highest concentrations of Ca were found in the treatments with the higher rate of slurry, also supplemented by PK fertilizers, and in the treatments with FYM. The soil liming treatment generally contributed to a large increase in the Ca concentration in tubers. A particularly high concentration of Ca was found in tubers fertilized with FYM, also supplemented by PK fertilizers (treatments F and G). In the tubers from these two treatments, the concentration of calcium rose by 0.30 and 0.29 mg, respectively, compared to the treatment without soil liming.

With a constant number of plants per hectare, in this experiment 40 thousands plants, the final yield of tubers depends on the number of tubers per plant and the average weight of one tuber, or the share of tubers in different weight (diameter) classes (Fig. 3). The number of tubers per plant was the highest in the treatment with mineral fertilizers (treatment H), followed by the treatments with slurry, and the lowest in treatments with FYM.



LSD $_{(\alpha=0.05)}$ for fertilization system 5.19 for liming 2.74 for interaction not significant

Fig. 3. *Effect of liming under different fertilization systems on the number and diameter of tubers per plant.*

Soil liming had a varied influence on the total number of tubers from a single plant. Potatoes harvested from the control plot and from the treatment with NPK (H) responded to liming by a significant increase of the total number of tubers per plant (Fig. 3), owing to a higher number of small tubers <4 cm: 136% and 53% more than in the unlimed and limed series, respectively. The results of our trials seem to verify the hypothesis expressed by Jackson [1999], who suggested that the presence of calcium stimulates tuber formation. The number of tubers obtained under the influence of a preceding soil liming treatment increased in relation to the unlimed series by an average of 2.1 tuber·plant^{-1}. On the plots amended with slurry rate I+PK (treatment C) and FYM+PK (treatment G), soil liming led to a smaller number of tubers per plant. This effect may be attributable to the supplementary phosphorus fertilization, with superphosphate which contains calcium.

Some other parameters of the yield structure are the size and/or weight of a single tuber. According to the regulations [Journal of Law, 2003], the minimum size of table potato tubers should be no less than 35 mm for round tubers. For oblong ones, the transverse diameter should be at least 30 mm while the longitudinal diameter should be double the length of the transverse one. In the authors' own research, tubers were divided into three fractions: less than 4cm, 4–6 cm and above 6 cm.The term „marketable tubers" refers to the two latter fractions. The structure of tuber yield has been expressed as the per cent share of weight of tubers in a given fraction versus the total weight of tubers (Table 2) or as the per cent share of the number of tubers in a given fraction versus the total number of tubers of all the analyzed fractions (Table 3). Marketable tubers made up on average 90% of the total weight of tuber yields both in the series with and without liming (Table 2). The share of large tubers, above 6 cm in diameter, in the yield was on average about 23% on soil without liming and around 29% on soil with limestone application. Moreover, liming largely reduced the share of small tubers, less than 4 cm in diameter. The best effect on the mass of marketable tubers was produced by the fertilization with the lower rate of slurry (treatment B) and slurry plus PK fertilizers (treatment C).

Table 2. *Effect of different fertilization systems on the structure of tuber yield, weight %*

Treatments		Without liming series			Liming series		
		<4 cm	4–6 cm	>6 cm	<4 cm	4–6 cm	>6 cm
A	Without fertilization	14.42	67.02	18.56	18.72	60.81	20.46
B	Slurry rate I	7.36	65.70	26.94	7.64	65.02	27.34
C	Slurry rate I +PK	8.00	63.33	28.67	8.00	50.89	41.11
D	Slurry rate II	9.38	68.63	21.99	8.34	62.92	28.74
E	Slurry rate II +PK	10.61	68.50	20.89	6.58	59.69	33.73
F	(FYM)	8.57	71.87	19.55	9.17	63.46	27.38
G	FYM+PK	9.34	69.54	21.12	10.35	62.12	27.53
H	NPK	7.83	67.01	25.15	9.99	62.99	27.02
	Mean	9.44	67.70	22.86	9.85	60.99	29.16

$LSD_{(\alpha=0.05)}$	Tuber size		
	<4 cm	4–6 cm	>6 cm
for fertilization system	2.95	n.s.	n.s.
for liming	n.s.	3.69	4.19
for interaction	n.s.	n.s.	n.s.

Regarding the quantitative aspect of tuber yield structure, each 100 tubers in the series without liming consisted of about 9% of large tubers, 65% medium-sized ones and 26% small tubers (Table 3). Liming contributed to some increase in the share of large tubers at the expense of medium ones, whereas the percentage of small tubers did not change. Soil liming applied to the plot which was annually amended with the higher rate of slurry and supplementary PK fertilization (treatment C) had the most favorable effect on tuber yields concerning the quantitative aspect.

Table 3. *Effect of different fertilization systems on the structure of tuber yield, quantitative %*

Treatments		Series without liming			Series with liming		
		<4 cm	4–6 cm	>6 cm	<4 cm	4–6 cm	>6 cm
A	Without fertilization	32.44	59.42	8.14	49.01	44.91	6.08
B	Slurry rate I	22.36	66.67	10.96	23.36	64.98	11.66
C	Slurry rate I +PK	26.40	61.46	12.14	13.94	65.93	20.13
D	Slurry rate II	27.38	64.31	8.32	23.56	63.63	12.81
E	Slurry rate II +PK	28.01	61.65	10.34	20.80	64.22	14.99
F	(FYM)	23.89	67.60	8.51	29.74	57.58	12.68
G	FYM+PK	26.63	65.26	8.11	28.12	60.07	11.81
H	NPK	23.56	68.83	7.62	29.19	61.70	9.11
	Mean:	26,33	64.40	9.27	27.21	60.38	12.41

	Tuber size		
$LSD_{(\alpha=0.05)}$	<4 cm	4–6 cm	>6 cm
for fertilization system	5.90	6.09	n.s.
for liming	n.s.	3.04	2.35
for interaction	8.35	n.s.	n.s.

Conclusions

1. The best effect on the volume of tuber yields was obtained by slurry rate II balanced with FYM in organic carbon and supplemented with PK mineral fertilizers. Additional soil liming, performed under winter wheat, significantly improved the yields of potato, especially the ones obtained from the above treatment.
2. The volume of marketable potato tubers was most positively affected by slurry rate I+PK. The weight share of marketable tubers (>4 cm) in this combination was 93.91%. In the limed series, the highest percentage of such tubers occurred under the influence of slurry rate II + PK, where it reached 93.44%.

3. Soil liming significantly raised the concentration of calcium in tubers, except the ones harvested from the plots treated annually with FYM or FYM + PK.
4. Potatoes harvested from the plots not treated with natural fertilizers (control object and the treatment with NPK) responded to liming by a significant increase of the total number of tubers per plant. This increase was achieved owing to a higher number of small tubers <4 cm (136% and 53% more than in the unlimed series, respectively).

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