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The impact of phosphorus seed coating on winter wheat at different fertilisation practices

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Abstract. Experiments with winter wheat (*Triticum aestivum* L.) were conducted during 2001/2002, 2002/2003 and 2003/2004 in Central Lithuania, Dotnuva site. The effect of P seed coating at control (without mineral fertilization), $(N_{17}P_{35}K_{87})$ N_{130} and $(N_{14}P_{70}K_{70})$ N_{130} fertilisation practices on a light loam soil testing low/moderate in available phosphorus was examined. P seed coating resulted in alteration to plant stand structure traits. Despite the fact that seedling emergence of P coated seed decreased, the number of total and productive stems and the number of grain per ear was identical to that of control. Significant changes in Zeleny sedimentation, wet and dry gluten, gluten index and falling number values resulting from P seed coating were obtained in the year with unfavourable wintering conditions. Although P seed coating exerted a positive effect on winter wheat early growth and influenced grain quality, it did not prove to be a method resulting in higher economic yield. The new hypothesis how to reduce phosphorus rate in conventional mineral fertilisation practice involving P seed coating needs further testing.

Key words: *Triticum aestivum* L., productivity components, yield, grain qualities

INTRODUCTION

The even seedling emergence followed by accelerated canopy closure are essential contributors to formation of yield potential (Peltonen–Sainio et al., 1997; Botwright et al., 2002; Richards & Lukacs, 2002). Germination vigour and seedling emergence depended on the amount and availability of grain endosperm reserves and on soil conditions. Soil moisture content is the key factor that determines onset of germination by enabling seed imbibition and thereby activating enzymes and stimulating their biosynthesis. This results in degradation of carbohydrates and other endosperm reserves. When the coleoptile breaks through the soil surface, followed by the unfolding of the first cotyledon leaf, the seedling begins to cease its dependence on endosperm reserves (Finch-Savage, 1955). Continued seedling growth is advanced by nutrients provided by fertilisers. Phosphorus and nitrogen are the key nutrients for crop growth. Seedling growth can be restricted by inadequate P availability (Grant et al., 2001). Fertiliser P only moves 3 to 5 cm from the application point (Khasawneh et al., 1974). Placing the fertiliser near or together with the seed may improve the ability of plants to utilize fertiliser P. An alternative approach is to coat cereal grain with a couple of mg of P per grain, which is equivalent to as much as 5 kg of P ha^{-1} before sowing (Scot et al., 1991). As a seedling growth promoter iSeed technology (referring to intelligent seed) was developed (Peltonen et al., 2004). Research on the efficacy of winter wheat P seed coating is scarce, since the history of such research is not long. By coating the seeds with soluble P fertiliser improved P use results in enhanced early root and seedling growth. Processes identified as having significant effect on wheat growth and development include nutrients uptake and metabolism, photosynthesis and respiration, carbon partitioning, leaf senescence, and plant water relations. Wheat grain yield is a function and integration of all these processes, each of which can be altered by the climatic conditions during the growing season and the cultural practices used to produce crop (Frederic & Bauer, 1999). Grain 'filling' lasts from its setting to ripening. Plant green leaf area and chlorophyll content in leaves are important for the synthesis of reserve grain substances during this period (Triboi & Triboi-Blondel, 2002; Martre et al., 2003). Organic substrates for grain growth may originate either from current assimilation or from storage (reserve) pools in vegetative plant parts (Schnyder, 1993). Still, pre-anthesis reserves may contribute significantly to grain yield even when conditions for photosynthesis are favourable during grain filling (Gebbing et al., 1999). P seed coating enhanced the total phytomass, number of stems and might enhance pre-anthesis reserves of storage pools. The weather conditions from anthesis to grain ripening have a marked effect on plants and can affect the yield and its quality much more markedly than the factors before anthesis. As a result, it is often difficult to prove at $P = 0.05$ level the efficacy of measures that improved initial plant growth. For example, oat P seed coating resulted in alteration to many plant stand structure traits, enhanced biomass accumulation (up to 22%) and grain set (up to 15%) without increasing economic yield (Peltonen-Sainio et al., 2006).

The objective of the present study was to estimate the effects of seed coating of winter wheat with phosphorus containing nutritious substances (P seed coating) on grain yield and elements shaping yield and on grain quality over three experimental years in the soil testing low/moderate in available phosphorus and potassium.

MATERIALS AND METHODS

Soil characteristics. The experiment was conducted on an endocalcaric-endohypogleyic cambisol neutral light loam soil in Dotnuva site of Central Lithuania over 2001/2002, 2002/2003 and 2003/2004 years. According to the conventional Lithuanian soil assessment method the soil was low (51–100 mg kg^{-1} P_2O_5/K_2O) and moderate (101–150 mg kg^{-1} P_2O_5/K_2O) in phosphorus and moderate in potassium (Lietuvos dirvožemių…, 1998). Content of trace elements in the soil was low/ moderate (Table 1).

Experimental design. Winter wheat (*Triticum aestivum* L.) cultivar 'Hereward' (UK origin) was tested. Preceding crops were winter rapeseed in 2002 and perennial grasses in 2003 and 2004. Seed rate was of 220 kg ha^{-1} of pure grain for control and P coated seed. Dates of sowing were 26^{th}, 20^{th} and 10^{th} of September in 2001, 2002 and 2003, respectively. Fertilisers *Kemira Gausa 10* (N: P_2O_5: K_2O rate 5:10:25) and *Kemira Gausa 20* (4:20:20) were applied at sowing. Rates of $N_{17}P_{35}K_{87}$ for *Kemira Gausa 10* and of $N_{14}P_{70}K_{70}$ for *Kemira Gausa 20* were used. P and K values for soil and fertiliser characteristics are reported as P_2O_5 and K_2O and for grain as pure P and K elements. Fertilisers were broadcast/placement applied. The drilling and fertiliser placement application machine was *Nordsten*. Depth of 3.5–4 cm was for seed sowing and of 7–8 cm for fertiliser placement. Control without mineral fertiliser application was included. Fertilisers and seed both P coated and uncoated control were obtained from the company Kemira GrowHow Vilnius stock.

Table 1. Soil characteristics. Dotnuva, 2002–2004.

Parameter	Method of analysis	Content in arable layer		
		2002	2003	2004
pH_{KCl}	Potentiometry in 1 M KCl extract	6.9	7.0	7.0
Humus %	Tyurin	2.1	2.1	2.2
P_2O_5 mg kg^{-1}	A–L (Egner–Riehm–Domingo)	97	88	118
K_2O mg kg^{-1}	A–L (Egner–Riehm–Domingo)	125	111	136
$N_{min}(N–NO_3+N–NH_4)$ in 0–40 cm layer kg ha^{-1}	$N–NH_4$ in KCl extract, by colorimetry $N–NO_3$ in water extract, by ionometry	29.0	42.5	41.0
S mg kg^{-1}	In KCl extract	1.5	0.9	1.9
B mg kg^{-1}	In hot water extract	0.84	0.7	0.78
Zn mg kg^{-1}	In HCl extract	0.85	0.72	0.50
Cu mg kg^{-1}	In HCl extract	3.7	3.1	3.7
Mo mg kg^{-1}	In ammonium oxalate extract	0.04	0.070	0.054

In spring at the resumption of growing period at BBCH 21 stage ammonium nitrate was broadcast. The rates of 274 (N_{93}) and 282 (N_{97}) kg ha^{-1} were applied, respectively when $N_{17}P_{35}K_{87}$ and $N_{14}P_{70}K_{70}$ were used. At the stage of BBCH 32 ammonium nitrate N_{30} was applied. Pesticide spray-application dates and doses are indicated in Table 2. Winter wheat was harvested on the 7th of July 2002, the 1st of August 2003 and the 7th of August 2004.

Table 2. Pesticide spray/application dates. Dotnuva, 2002–2004.

Year	Date	Product used
2002	26th of April	Harmony Extra 0.02 kg ha^{-1}+Cytovet 100 ml ha^{-1}+Kemira CCC 1.5 l ha^{-1}
	16th of May	Archer 1.0 l ha^{-1}
	6th of June	Juventus 1.25 l ha^{-1}
2003	13th of May	Primus 0.1 l ha^{-1}+Granstar 10 g ha^{-1}+Kemivet 1.0 l ha^{-1}
	19th of May	Mentor 0.7 l ha^{-1}+Fastac 0.1 l ha^{-1}
	11th of June	Juventus 1.5 l ha^{-1}+ Fastac 0.1 l ha^{-1}
2004	28th of April	Mustang 0.6 l ha^{-1}+Kemivet 1.0 l ha^{-1}
	7th of May	Sfera 0.8 l ha^{-1}+ Mentor 0.5 l ha^{-1}+ Fastac 0.1 l ha^{-1}
	16th of June	Juventus 1.5 l ha^{-1}+ Fastac 0.1 l ha^{-1}

Sampling measurements and analysis. The trials included four replicates. Crop establishment was evaluated in the autumn as a number of seedlings m^{-2}. In the autumn of 2002 the number of seedlings was very low, because not all seedlings emerged. They were in the soil and only in the spring of 2003 emerged on the soil surface. Therefore they were counted in early spring in 2003 and these data were used for statistics. The total number of stems (TT), productive stems (PT) and non productive tillers (NT) and the number of grain per ear of productive stems were counted in pulled plants from each plot in two rows of one longitudinal meter (0.25 m^2) before harvesting. The plots were harvested by a harvester Sampo–500 and grain samples for analyses were collected. One thousand grain weight (TGW) (ISO 580), grain protein (GP) (total nitrogen by Kjeldahl multiplied by 5.7) (ICC 105/2), wet gluten content (WG), gluten quality (GI) by Glutomatic and centrifuge, dry gluten (DG) content (ICC 155), sedimentation by Zeleny (ZS) (ICC 116/1, 118), falling number (FN) according to Hagberg–Perten (ICC 107/1), after wet destruction phosphorus (P) (by colorimetry) and potassium (K) (by flame photometry) were determined. Yield data were adjusted to 15 % moisture content, grain quality characteristics were determined in dry grain. The number of grain in million per hectare (mio ha^{-1}) was calculated from the data of combine–harvested grain yield and TGW.

Statistical analysis. The results were analysed using the software package ANOVA. For two factors analysis for data at control fertilisation (without fertiliser) practice A factor was crop year and B factor control and P coated seed. For three factors analysis for fertilised treatments: A factor – fertilisers *Kemira Gausa 20* and *Kemira Gausa 10*, B factor – broadcast and placement applied, C factor – control and P coated seed. LSD criterion and probabilities *P* for nil hypothesis rejection were calculated using Fisher's-test and $P < 0.05$ (Clewer & Scarisbrick, 2001).

RESULTS AND DISCUSSION

Weather conditions. According to the data from the Dotnuva weather station the weather conditions in 2001 were favourable for winter wheat germination. Wintering was favourable too. At the resumption of growth in the spring of 2002 there was enough moisture in the soil, but later dry period followed. In July the hot weather and short supply of water resulted in the drying up of leaves and stems. The flow of products from the leaves and stems to the grain was interrupted although the grains were immature. Grain was harvested exclusively early.

In the autumn of 2002 soil moisture content was insufficient for normal sprouting. Later the cold weather prevailed and shoots did not appear, therefore the effect of environmental conditions on the rate of leaf appearance was evident. However, seedlings rooted in the ground but the leaves of some plants appeared in early spring only. In the spring of 2003 the air temperature 5–13°C below zero frosted the stand, which turned brown. Despite this, the roots of plants were developed and plants started growing quickly. At the end of April the winter wheat stand was of normal density. In May the growing conditions were favourable. At the beginning of June the plants were short of moisture. Grain was harvested at conventional time.

In September 2003 warm, dry and sunny weather prevailed. The monthly amount of rainfall was only 41% of the long–term mean. The conditions for winter wheat sowing and germination were poor. The growing season resumed in the first ten–day period of March but the intensive growth of the plants started only in the second ten-day period of April. In May and June the weather conditions were cooler and dryer compared with the long–term mean. In June plants were short of moisture. In July the weather was cooler and humidity was higher than the long–term mean. Only in the third ten–day period of July the weather became slightly warmer. On the 28th of July the grain was at early milk stage. On the 7th of August the grain was completely ripe and was harvested. The summarised data of the weather conditions of the three years suggest that in 2002 and 2003 crop year winter wheat plants were short of soil moisture. In 2002 grain ripened very early. In 2004 the weather was cooler and there were fewer sunny days compared with the years 2002 and 2003.

P seed coating effect at without fertilisation practice. At without mineral fertilisation (control) practice P seed coating did not affect significantly crop establishment (Table 3).

Table 3. Effect of P seed coating at $N_0P_0K_0$ mineral fertilisation practice. Dotnuva, 2002–2004.

Trait	2002		2003		2004		3 years' mean		
	control	coated	control	coated	control	coated	control	coated	*P*
Seedling no. m^{-2}	406.0ab	360.5a	469.0b	465.0b	382.5a	372.5a	419.0	399.3	0.27
TT no. m^{-2}	397.0a	399.5a	435.0ab	478.5b	463.0ab	443.0ab	431.7	440.3	0.67
PT no. m^{-2}	366.0ab	378.0bc	321.5a	351.0a	423.5c	407.0bc	370.3	378.7	0.56
NT no. m^{-2}	31.0 a	21.5 a	113.5b	127.5b	39.5a	36.0a	61.3	61.7	0.98
Grain ear^{-1}	30.78ab	33.75bc	36.03c	27.85a	34.75c	36.05c	33.86	32.55	0.15
TGW g	43.89a	43.64a	45.21b	45.18b	46.34c	45.81bc	45.14	44.88	0.19
Yield t ha^{-1}	5.37b	5.48b	4.37a	4.55a	5.71b	5.83b	5.15	5.29	0.36
GP %	10.33b	10.05b	10.39b	9.69b	8.69a	8.65a	9.80	9.46	0.19
ZS cm^3	25.0b	23.5b	32.1c	24.3b	20.5a	20.0a	25.9	22.6	**
WG %	20.6b	18.4ab	22.6b	17.9ab	16.4a	17.0a	19.9	17.8	*
GI unit	79.3ab	86.5b	65.8a	89.5b	81.1ab	85.4b	75.4	87.2	*
DG %	6.52bc	5.48a	6.98c	5.67ab	5.64ab	5.38a	6.38	5.51	**
FN s	380.0cd	346.8b	394.5d	363.8bc	314.5a	290.8a	362.2	333.8	**
Grain mio ha^{-1}	122.3b	125.5b	96.5a	100.7a	123.3b	127.4b	114.1	117.9	0.26
$Ngrain^{-1}$ µg	692.1c	671.1bc	718.0c	667.5abc	614.2ab	604.9a	674.8	647.9	0.18
$Pgrain^{-1}$ µg	108.2a	112.2a	143.7c	142.3c	127.6b	131.8b	126.5	128.8	0.42
$Kgrain^{-1}$ µg	187.8abc	193.2bc	181.1ab	177.0a	191.6bc	198.6c	186.8	189.6	0.46
P %	0.283a	0.296a	0.365c	0.362c	0.317b	0.331b	0.320	0.330	0.18
K %	0.492bc	0.509c	0.460a	0.450a	0.475ab	0.498bc	0.480	0.490	0.21

Means within 2002, 2003 and 2004 period not followed by the same letter are significantly different at $P < 0.05$.

The three years' mean data indicate that sowing of P coated seed resulted in a decrease in Zeleny sedimentation, wet and dry gluten and falling number values. The gluten quality increased. A variation of these quality traits was related to insufficient supply of nitrogen. It was demonstrated by a single grain N content of 600–700 µg at a number of grains per hectare of 100–130 million.

The hypothesis that P seed coated winter wheat started growth with higher potential compared with control is supported by grain yield data, which was by

0.14 t ha^{-1} higher. Therefore, shortage of nitrogen over the post–anthesis period and a slightly higher number of combine–harvested grains per area in P seed treated plots led to a decrease in those grain quality indices, which are known to be strongly related to the nitrogen supply.

Statistical analysis to study nil hypothesis rejection of fertilisers, application strategy and P seed coating effects. According to the probability criterion P and K doses and rate in applied fertilisers had the strongest effect on many traits studied (Table 4). The influence of the weather conditions over experimental years was substantial too. Statistical analysis demonstrated that the impact of fertiliser type applied was diverse in separate years. The effect of fertilizer placement application was similar to that of broadcast.

Table 4. Probability levels for the nil hypothesis rejection for the effects of fertilisers *Kemira Gausa 20* ($N_{14}P_{70}K_{70}$) and $N_{17}P_{35}K_{87}$ *(Kemira Gausa 10)* (A factor) and application type (broadcast, placement) (B factor). Dotnuva, 2002–2004.

Trait	Probability *P*							
	A factor				B factor			
	2002	2003	2004	3 years' mean	2002	2003	2004	3 years' mean
Seedling no. m^{-2}	0.02	0.63	0.71	0.26	0.21	*	0.21	0.66
PT no. m^{-2}	0.17	**	0.27	0.61	0.52	0.71	0.64	0.58
NT no. m^{-2}	0.71	0.13	*	0.06	0.30	0.12	0.53	0.31
Grain no. ear^{-1}	*	0.30	*	**	**	0.62	0.60	0.06
TGW g	0.05	*	0.32	0.26	0.45	*	**	0.83
Grain yield t ha^{-1}	0.07	0.07	**	**	0.68	0.77	0.45	0.54
GP %	**	**	**	**	0.63	0.91	*	0.69
ZS cm^3	**	**	0.20	**	0.32	*	0.74	0.31
DG %	**	**	0.55	**	0.25	0.21	0.63	0.78
GI unit	**	**	0.23	**	0.11	0.74	0.06	0.63
DG %	**	**	0.48	**	0.21	0.16	0.15	0.53
FN s	**	0.08	0.39	**	*	0.60	0.07	0.76
Grain mio ha^{-1}	*	0.26	**	**	0.78	0.30	0.16	0.57
N $grain^{-1}$ μg	**	**	*	**	0.44	0.49	**	0.83
P $grain^{-1}$ μg	0.14	*	0.84	*	0.80	0.09	*	0.54
K $grain^{-1}$ μg	0.75	0.75	**	0.28	0.86	0.41	**	0.30
P %	0.07	0.97	0.82	0.29	0.68	0.35	0.26	0.79
K %	0.37	0.30	*	0.51	0.69	0.97	*	0.23

Crop establishment was a very critical factor in P seed coating (Table 5). P seed coating effects on stand and grain quality traits were mostly evident in 2003.

P seed coating effects at $N_{14}P_{70}K_{70}$ (Kemira Gausa 20) fertilisation practice. Despite the essentially lower number of productive stems in 2002, the slight positive effect of P seed coating on the increase in grain number per ear and TGW resulted in grain yield equal to that of control (Table 6). In 2003 year P seed coating positively influenced tillering and compensated for the lower seedling emergence. Sowing of P coated seed slightly increased wet and dry gluten content and falling number values. In 2004 a grain yield of over 8 t ha^{-1} was obtained. It was the highest yield compared with the other experimental years. The grain yield and quality of wheat sown P coated was similar to those of control.

Table 5. Probability levels for the nil hypothesis rejection for the effects of P seed coating (C factor). Dotnuva, 2002–2004.

Trait	Probability *P* for P seed coating (C factor)			
	2002	2003	2004	mean
Seedling no. m^{-2}	**	*	*	**
PT no. m^{-2}	*	0.07	0.60	0.30
NT no. m^{-2}	0.71	0.81	0.59	0.82
Grain no. ear^{-1}	0.10	*	0.76	0.40
TGW g	0.32	0.54	*	0.18
Grain yield t ha^{-1}	0.79	0.54	0.61	0.56
GP %	0.79	0.26	*	0.79
ZS cm^3	0.22	*	0.74	0.07
DG %	0.89	**	0.22	0.13
GI unit	0.54	*	0.41	0.30
DG %	0.80	*	0.18	0.17
FN s	0.21	**	0.80	*
Grain mio ha^{-1}	0.58	0.45	0.28	0.34
N $grain^{-1}$ µg	0.57	0.37	**	0.87
P $grain^{-1}$ µg	0.83	0.08	0.14	0.13
K $grain^{-1}$ µg	0.24	0.89	0.60	0.78
P %	0.96	*	0.65	0.15
K %	0.42	0.98	0.30	0.39

Table 6. The effect of P seed coating as affected by *Kemira Gausa 20* ($N_{14}P_{70}K_{70}$) fertilisation. Dotnuva, 2002–-2004.

Trait	2002		2003		2004		3 years' mean		
	control	coated	control	coated	control	coated	control	coated	*P*
Seedling, no. m^{-2}	383.0a	340.6b	492.8b	462.0a	374b	352a	416.6	384.9	**
TT no.m^{-2}	471.5b	413.5a	528.3a	544.5a	523.0a	539.8a	507.6	499.3	0.51
PT no.m^{-2}	450.0b	402.8a	484.8a	494.8a	502.3a	510.8a	479.0	469.4	0.43
NT no.m^{-2}	22.5a	16.0a	47.3a	49.8a	20.8a	29.0a	30.2	31.6	0.67
Grain ear^{-1}	36.15a	37.84a	42.40a	40.66a	37.7a	37.2a	38.7	38.6	0.82
TGW g	43.29a	43.36a	44.81a	44.75a	47.06a	46.90a	45.05	45.00	0.83
Yield t ha^{-1}	7.11a	7.19a	7.45a	7.37a	8.17a	8.22a	7.57	7.59	0.90
GP %	10.48a	10.51a	11.4a	11.6a	9.87a	9.76a	10.6	10.6	0.75
ZS cm^3	28.38a	29.44a	37.1a	38.6a	25.1a	25.0a	30.2	31.0	0.15
WG %	20.1a	19.9a	24.3a	25.7b	20.8a	20.6a	21.7	22.1	0.28
GI unit	79.0a	83.1a	66.5a	61.8a	62.5a	61.8a	69.3	68.9	0.84
DG %	6.22a	6.25a	7.50a	7.87b	6.57a	6.55a	6.76	6.89	0.22
FN s	370.3a	377.8a	385.8a	404.9b	332.6a	327.0a	362.9	369.9	**
Grain mio ha^{-1}	164.2a	165.9a	166.2a	164.7a	173.5a	175.1a	168.0	168.6	0.85
N $grain^{-1}$ µg	691.8a	695.2a	778.8a	793.2a	708.7a	698.8a	726.5	729.1	0.82
P $grain^{-1}$µg	100.6a	104.2a	135.0a	133.7a	129.0a	127.7a	121.5	121.8	0.83
K $grain^{-1}$ µg	185.6a	186.7a	175.7a	178.5a	191.3a	190.3a	184.2	185.2	0.68
P %	0.267a	0.276a	0.353a	0.342a	0.315a	0.313a	0.312	0.310	0.75
K %	0.493a	0.495a	0.451a	0.458a	0.467a	0.466a	0.470	0.473	0.63

Means within each experimental year not followed by the same letter are significantly different at $P < 0.05$.

P seed coating effects at $N_{17}P_{35}K_{87}$ *(Kemira Gausa 10) fertilisation practice*. Three years' mean revealed a problem of seedling emergence, similar to that as at the without fertilisers and *Kemira Gausa 20* fertilisation practices, therefore a special attention should be directed to the coated seed flowability issue. On the other hand, the higher concentration of the salt in soil when P coated seed used could affect seedling emergence.

Winter wheat received a lower rate of phosphorus and higher rate of potassium when *Kemira Gausa 10* ($N_{17}P_{35}K_{87}$) was applied compared with *Kemira Gausa 20* ($N_{14}P_{70}K_{70}$). The grain yield higher by 0.46 t ha^{-1} when *Kemira Gausa 10* was applied (Tables 6 & 7) demonstrated the importance of potassium in proportion to phosphorus for winter wheat growth. Despite this, winter wheat is reported as the crop most sensitive to phosphorus rates in Lithuania (Vaisvila et al., 2000). Therefore P seed coating could compensate for the shortage of the element.

Sowing P coated seed slightly affected grain qualities (Table 7). It was evident in 2003 when the weather conditions were poor for winter wheat initial growth.

Table 7. Effect of P seed coating at *Kemira Gausa 10* $N_{17}P_{35}K_{87}$ fertilisation. Dotnuva, 2002–2004.

Trait	2002		2003		2004		3 years' mean		
	control	coated	control	coated	control	coated	control	coated	*P*
Seedling no. m^{-2}	412.0a	354.3b	484.5a	478.3a	366.0a	354.8a	420.8	395.8	**
TT no.m^{-2}	467.3a	469.4a	494.0a	510.3a	559.9a	528.0a	507.0	502.5	0.73
PT no. m^{-2}	451.3a	437.5a	455.3a	474.5a	538.9a	512.3a	481.8	474.8	0.42
NT no.m^{-2}	16.0a	24.6b	43.8a	39.0a	21.0a	15.8a	26.9	26.5	0.86
Grain ear^{-1}	38.34a	38.50a	44.46b	40.91a	39.20a	40.40a	40.70	39.90	0.34
TGW g	42.81a	43.12a	45.59a	45.29a	47.85b	46.65a	45.42	45.02	0.35
Yield t ha^{-1}	7.48a	7.33a	7.57a	7.83a	8.89a	9.07a	7.98	8.08	0.47
GP %	11.34a	11.40a	12.1a	12.4a	9.66a	9.32a	11.0	11.0	0.92
ZS cm^3	32.5a	32.81a	39.6a	42.2b	24.6a	24.5a	32.3	33.2	0.12
WG %	22.2a	22.3a	26.0a	27.7b	20.8a	20.2a	23.0	23.4	0.13
GI unit	75.3b	69.0a	56.5a	51.6a	57.6a	61.7a	63.1	60.8	0.05
DG %	7.02a	7.06a	7.93a	8.41b	6.61a	6.38a	7.18	7.28	0.27
FN s	386.6a	387.5a	398.9a	406.5a	331.4a	335.0a	372.3	376.3	0.42
Grain mio ha^{-1}	174.6a	169.9a	166.1a	172.9a	186.0a	194.4a	175.6	179.1	0.23
N grain^{-1}µg	741.2a	750.5a	839.5a	856.3a	706.2b	663.4a	762.3	756.7	0.58
P grain^{-1} µg	106.6a	103.8a	139.6a	135.7a	130.6a	126.7a	125.6	122.1	**
K grain^{-1}µg	184.6a	189.4a	178.0a	173.9a	196.8a	195.8a	186.5	186.4	0.96
P %	0.286a	0.277a	0.352a	0.343a	0.314a	0.312a	0.317	0.311	0.07
K %	0.496a	0.505a	0.449a	0.442a	0.473a	0.482a	0.472	0.476	0.35

Means within each experimental year not followed by the same letter are significantly different at $P < 0.05$.

P seed coating effects at mineral fertiliser broadcast and placement application. Fertiliser placement application didn't affected seedling emergency (Table 8). It leads to conclusion that P seed coating influence on salt concentration in soil was negligible when *Kemira Gausa 20* and *Kemira Gausa 10* placement application had been used.

The effect of P seed coating on the other examined traits at placement application was similar to that of broadcast applied fertiliser.

Table 8. Effect of interaction fertiliser x broadcast/placement application x P seed coating. Dotnuva, 2002–2004.

Trait	$N_{14}P_{70}K_{70}$ *(Kemira Gausa 20)*				$N_{17}P_{35}K_{87}$ *(Kemira Gausa 10)*				LSD_{05}
	Broadcast		Placement		Broadcast		Placement		
	control	coated	control	coated	control	coated	control	coated	
Seedling no. m^{-2}	413.0	378.4	420.2	391.3	423.0	397.8	418.7	393.7	26.5
TT no.m^{-2}	500.2	500.7	515.0	497.8	513.0	518.0	501.1	487.1	38.4
PT no.m^{-2}	473.7	469.3	484.3	469.5	485.8	485.0	477.8	464.5	31.6
NT no.m^{-2}	29.0	31.7	31.3	31.5	28.3	30.5	25.5	22.4	8.54
Grain no ear^{-1}	39.6	38.5	37.9	38.7	41.0	40.9	40.3	39.0	2.20
TGW g	45.06	44.79	45.05	45.21	45.54	45.03	45.29	45.01	0.670
Yield t ha^{-1}	7.46	7.59	7.69	7.60	8.01	8.04	7.95	8.11	0.390
GP %	10.6	10.7	10.6	10.6	11.1	11.0	10.9	11.1	0.50
ZS cm^3	30.0	31.2	30.4	30.9	33.0	33.5	31.5	32.9	1.90
WG %	21.5	22.2	21.9	21.9	23.2	23.4	22.8	23.5	1.00
GI unit	68.5	67.6	70.2	70.2	63.8	60.9	62.4	60.7	5.30
DG %	6.70	7.00	6.82	6.78	7.26	7.26	7.11	7.30	0.32
FN s	361.0	367.1	364.8	372.7	374.8	379.9	369.8	372.8	9.40
Grain, mio ha^{-1}	165.5	169.2	170.5	167.9	175.8	178.2	175.3	179.9	8.50
N $grain^{-1}$µg	725.4	727.1	727.5	731.0	771.6	754.3	753.0	759.2	34.5
P $grain^{-1}$ µg	121.6	120.7	121.4	123.0	127.5	122.5	123.7	121.7	4.20
K $grain^{-1}$ µg	184.8	182.1	183.6	188.2	190.7	187.9	182.2	184.9	6.40
P %	0.310	0.309	0.314	0.312	0.321	0.312	0.313	0.310	0.011
K %	0.472	0.468	0.469	0.479	0.482	0.480	0.463	0.473	0.016

We concluded that due to the lower flowability of P coated seed attention should be paid to the seed rate adjustment before sowing by checking the seed feeding rate for every drilling machine. The toxic effect of P seed coating for crop establishment was possible in exclusively dry conditions. Although seed coating slightly decreased seedling emergence, it supported early growth vigour. The idea that P seed coating results in higher biomass production of cereal stands is supported by the findings of Peltonen et al., (2004) and Peltonen–Sainio et al. (2006). The effect of P seed coating on winter wheat was demonstrated by the grain quality data. The statistically significant changes in falling number could be related to P seed coating effect on the wheat rooting and therefore on the nitrogen uptake. The falling number for grain of P coated seed at without NPK fertilisation decreased. It could be the result of higher grain number per area and therefore lower nitrogen content per grain. The lower nitrogen content resulted in alpha–amylase activity increase in the absence of sprouting (Kettlewell, 1999). Winter wheat receiving little or no nitrogen increases alfa–amylase activity. N fertilised wheat dried faster and reduced alfa–amylase activity. In fertilised plots wheat sown P seed coated might increase grain drying rate during maturity period, thereby reduced pre-maturity alfa–amylase activity. This might account for the effect of P seed coating on increasing falling number in 2002 and 2003. In 2004 wheat was harvested later, therefore pre-maturity alfa–amylase formation was reduced and no differences in falling number were obtained. Grain sedimentation and wet and dry gluten as well as gluten index data confirmed that winter wheat stand was affected when sowing P seed coated seed. The economic yield of P coated treatments was equal to that of control. It was determined that the increase in grain weight averaged for 11–12% for control and 6–9% for P coated seed in favour of hand–threshed compared with combine–harvested was obtained. This demonstrated that small grains were lost during harvest, which may somewhat diminish the differences in grain yield.

CONCLUSION

Although P seed coating had positive effect on winter wheat early growth on low/moderate in available phosphorus soils and influenced grain quality, it did not prove to be a method resulting in higher economic yield. A new hypothesis to reduce phosphorus rate in conventional mineral fertilisation practice when P seed coating used should be examined with future studies.

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