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EFFECT OF FERTILIZING SYSTEMS ON THE PHOSPHORUS EFFICIENCY INDICATORS AT DURUM WHEAT

SUMMARY

The main agronomic indicators of effectiveness for phosphorus fertilizing alone or combined with nitrogen fertilization N_{120} in durum wheat grown in conditions of long term fertilizing experiment in two field crops rotation cotton – durum wheat under rain conditions for the period of three vegetations including years 2011 – 2013 were studied. The Latin square method as experimental design with trial plot size $50m^2$ in four replications was used. The examined fertilizing systems were as follows: N_0P_0; N_0P_{80}; N_0P_{120}; N_0P_{160}; $N_{120}P_{80}$; $N_{120}P_{120}$; $N_{120}P_{160}$. Nitrogen fertilization as NH_4NO_3 was applied early spring. The phosphorus fertilization was applied before sowing as triple superphosphate. The soil type of experimental field was Eutric vertisols. Weather conditions during the studied period 2011 – 2013 were different as a temperature and rainfall each year.

Indexes partial factor productivity (PFP), agronomic efficiency (AE), apparent crop recovery (RE), partial nutrient balance (PNB), and physiological efficiency of applied phosphorus (PE) were studied. It was established that fertilizing systems of durum wheat strongly affect the indicators of phosphorus efficiency. The partial factor productivity of phosphorus changed from 13.4 to 51.8 kg grain per kg P_2O_5 applied in dependence of the fertilizing system. The average agronomic efficiency was varied in range 1.6-28.1 kg grain and 0.20-4.58 kg grain protein for the experimental period. Apparent crop recovery efficiency of applied phosphorus (kg increase in P uptake per kg P applied) was very low 0.11-0.15 $kg.kg^{-1}$ when wheat was grown with no nitrogen fertilization. Recovery efficiency and physiological efficiency of applied P (kg yield increase per kg increase in P uptake from fertilizer) did not depend of the quantity of applied phosphorus P_{80}-P_{160} in systems without nitrogen. Alone phosphorus fertilizing in rates 80-160 kg $P_2O_5.ha^{-1}$ demonstrated lower efficiency of phosphorus expressed as calculated indicators partial factor productivity, agronomic efficiency, apparent crop recovery, partial nutrient balance, and physiological efficiency. Systematic fertilization of durum wheat in rates $N_{120}P_{80}$ was the most effective in average for the experimental period.

Keywords: phosphorus efficiency indicators, durum wheat.

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INTRODUCTION

Nutrient use efficiency can be expressed several ways. Mosier et al. (2004) described 4 agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Crop removal efficiency (removal of nutrient in harvested crop as % of nutrient applied) is also commonly used to explain nutrient efficiency. Available data and objectives determine which term best describes nutrient use efficiency. Fixen (2005) provides a good overview of these different terms with examples of how they might be applied.

Fertilizer nutrients applied, but not taken up by the crop, are vulnerable to losses from leaching, erosion, and denitrification or volatilization in the case of N, or they could be temporarily immobilized in soil organic matter to be released at a later time, all of which impact apparent use efficiency. Dobermann et al. (2005) introduced the term system level efficiency to account for contributions of added nutrients to both crop uptake and soil nutrient supply.

Fertilizer use efficiency can be optimized by fertilizer best management practices that apply nutrients at the right rate, time, and place. The highest nutrient use efficiency always occurs at the lower parts of the yield response curve, where fertilizer inputs are lowest, but effectiveness of fertilizers in increasing crop yields and optimizing farmer profitability should not be sacrificed for the sake of efficiency alone. There must be a balance between optimal nutrient use efficiency and optimal crop productivity (Roberts 2008).

While most of the focus on nutrient efficiency is on N, phosphorus (P) efficiency is also of interest because it is one of the least available and least mobile mineral nutrients. First year recovery of applied fertilizer P ranges from less than 10% to as high as 30%. However, because fertilizer P is considered immobile in the soil and reaction (fixation and/or precipitation) with other soil minerals is relatively slow, long-term recovery of P by subsequent crops can be much higher (Roberts 2008).

Greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N. Split applications of N during the growing season, rather than a single, large application prior to planting, are known to be effective in increasing N use efficiency (Cassman et al., 2002).

A recent review of worldwide data on N use efficiency for cereal crops from researcher-managed experimental plots reported that single-year fertilizer N recovery efficiencies averaged 65% for corn, 57% for wheat, and 46% for rice (Ladha et al., 2005). Cassman et al. (2002) looked at N fertilizer recovery under different cropping systems and reported 37% recovery for corn grown in the north central U.S.

MATERIAL AND METHODS

The investigation was studied under conditions of long term fertilizing experiment. The standard variety „Progress", selected in Institute of field crops – Chirpan town, Bulgaria was grown in two field crops rotation cotton – durum wheat under rain conditions for the period of three vegetations including years 2011 – 2013. The experimental design was the method of Latin square with trial plot size 50m^2 in four replications. The treatments were as follows: N_0P_0; N_0P_{80}; N_0P_{120}; N_0P_{160}; $N_{120}P_{80}$; $N_{120}P_{120}$; $N_{120}P_{160}$. Nitrogen fertilization as NH_4NO_3 was applied early spring. The phosphorus fertilization was applied before sowing as triple superphosphate. The soil type of experimental field was Eutric vertisols.

RESULTS AND DISCUSSION

The values of the partial factor productivity of phosphorus for grain and grain protein decreased with increasing of phosphoric fertilizer rate, independently whether the element was applied alone or in combination with nitrogen.

In the studied period 2011 - 2013 was established, that the average partial factor productivity of phosphorus was highest in phosphorus fertilization 80 kg.ha^{-1} combined with N_{120} for grain and grain protein - respectively 51.8 and 7.5 kg.kg^{-1} and proven exceed the values shown in all other fertilization systems. When researched the same phosphoric rate, but excluded nitrogen of the system was established, that the values of partial factor productivity were significantly lower - 97% for grain and 127% for grain protein. Phosphorus use effectiveness of the plants was lowest in alone phosphoric fertilization in rate 160 kg.ha^{-1}, as the values of partial factor productivity were lowest for grain and grain protein – 13.4 and 1.7 kg.kg^{-1}, respectively 287 and 341% less than $N_{120}P_{80}$. The obtained higher values of phosphorus partial factor productivity in systems combined with nitrogen fertilization 120 kg.ha^{-1} were due to the high effect of nitrogen for the formation of higher grain and grain protein yields (Tab. 1).

Average for the period 2011 - 2013 agronomic efficiency of phosphorus for grain and grain protein decreased with increasing phosphorus rate in systems with included nitrogen. The effect of 1 kg phosphorus fertilizer in the system $N_{120}P_{80}$ was obtained 28.1 kg wheat grain and 4.58 kg grain protein, which was proven agronomic most effective fertilization system. This effect was reduced approximately two-fold in doubling of applied phosphorus - 107% for grain and 110% for grain protein. The agronomic efficiency values dropped off significantly in fertilization systems excluded nitrogen, as the lowest was in alone phosphorus fertilization with 180 kg.ha^{-1}- 1.6 kg.kg^{-1}for grain and 0.20 kg.kg^{-1} for grain protein.

The higher values for the agronomic efficiency of phosphorus in systems with combined nitrogen-phosphorus fertilization was due to the effect of nitrogen on the formation of higher yields (Tab. 2).

Table 1. Partial factor productivity (PFP) of phosphorus for grain and grain protein (kg P_2O_5/kg) depends on the fertilization system in cultivar Progress

A. Fertilization system	2011	2012	2013	Average for the period
Partial factor productivity of phosphorus for grain				
N_0P_{80}	20.8	34.9	23.4	26.3 bc
N_0P_{120}	15.3	24.6	19.1	19.6 cd
N_0P_{160}	11.8	16.0	12.5	13.4 d
$N_{120}P_{80}$	60.5	51.5	43.5	51.8 a
$N_{120}P_{120}$	41.6	36.0	30.3	36.0 b
$N_{120}P_{160}$	30.5	25.3	20.7	25.5 bc
B. Year	30.1 ns	31.4	24.9	
Partial factor productivity of phosphorus for grain protein				
N_0P_{80}	2.6	4.3	2.9	3.3 c
N_0P_{120}	1.9	3.1	2.4	2.5 cd
N_0P_{160}	1.5	2.0	1.5	1.7 d
$N_{120}P_{80}$	9.0	7.2	6.3	7.5 a
$N_{120}P_{120}$	6.4	5.3	4.6	5.4 b
$N_{120}P_{160}$	4.5	3.5	3.0	3.6 c
B. Year	4.3 ns	4.2	3.5	

Table 2. Agronomic efficiency (AE) of phosphorus for grain and grain protein (kg P_2O_5/kg) depends on the fertilization system in cultivar Progress

A. Fertilization system	2011	2012	2013	Average for the period
Agronomic efficiency of phosphorus for grain				
N_0P_{80}	0.6	4.8	2.5	2.6 d
N_0P_{120}	1.8	4.5	5.1	3.8 cd
N_0P_{160}	1.8	0.9	2.0	1.6 d
$N_{120}P_{80}$	40.4	21.3	22.6	28.1 a
$N_{120}P_{120}$	28.2	16	16.4	20.2 ab
$N_{120}P_{160}$	20.5	10.2	10.2	13.6 bc
B. Year	15.6 ns	9.6	9.8	
Agronomic efficiency of phosphorus for grain protein				
N_0P_{80}	0.11	0.66	0.34	0.37 c
N_0P_{120}	0.26	0.63	0.68	0.52 c
N_0P_{160}	0.23	0.13	0.24	0.20 c
$N_{120}P_{80}$	6.48	3.58	3.70	4.58 a
$N_{120}P_{120}$	4.68	2.82	2.83	3.44 ab
$N_{120}P_{160}$	3.21	1.68	1.66	2.18 b
B. Year	2.50 ns	1.60	1.60	

Average for all studied period in cultivar Progress highest apparent recovery efficiency of phosphorus was obtained in the combined fertilization system $N_{120}P_{80}$ – 0.58 $kg.kg^{-1}$ for grain + straw and 0.33 $kg.kg^{-1}$ for grain. In combined fertilization the values of the indicator apparent recovery efficiency

decreased with increasing phosphorus rate, as was proven lower in the system $N_{120}P_{160}$ (by 71% for grain + straw and 74% for grain) compared to $N_{120}P_{80}$. In the systems excluded nitrogen the values of apparent recovery efficiency were proven and significantly lower (for grain + straw was in range 0.11 – 0.15 kg.kg^{-1}, and for grain 0.05 – 0.08 kg.kg^{-1}), compared to combined fertilization systems. Apparent recovery efficiency in the system $N_{120}P_{80}$ was higher with 427% for grain + straw and 560% for grain compared to the efficiency in alone phosphorus fertilization with 160 kg.ha^{-1}, which shown the high effect of nitrogen for apparent recovery efficiency of phosphorus for plants and grain.

The higher values of apparent recovery efficiency of phosphorus in the systems with nitrogen fertilization 120 kg.ha^{-1} due to the effect of nitrogen on biomass production, mobilization and utilization of more phosphorus of plants from the soil reserves (Tab 3).

Table 3. Apparent recovery efficiency (RE) of phosphorus in grain+straw and grain (kg P_2O_5/kg) depends on the fertilization system in cultivar Progress

A. Fertilization system	2011	2012	2013	Average for the period
Apparent recovery efficiency of phosphorus in grain+straw				
N_0P_{80}	0.10	0.22	0.13	0.15 c
N_0P_{120}	0.10	0.19	0.17	0.15 c
N_0P_{160}	0.10	0.11	0.11	0.11 c
$N_{120}P_{80}$	0.76	0.51	0.47	0.58 a
$N_{120}P_{120}$	0.57	0.41	0.36	0.45 ab
$N_{120}P_{160}$	0.46	0.31	0.27	0.34 b
B. Year	0,35 ns	0.29	0.25	
Apparent recovery efficiency of phosphorus in grain				
N_0P_{80}	0.06	0.12	0.07	0.08 c
N_0P_{120}	0.05	0.10	0.09	0.08 c
N_0P_{160}	0.05	0.06	0.05	0.05 c
$N_{120}P_{80}$	0.44	0.28	0.27	0.33 a
$N_{120}P_{120}$	0.32	0.22	0.20	0.25 ab
$N_{120}P_{160}$	0.26	0.16	0.15	0.19 b
B. Year	0.20 ns	0.16	0.14	

Depends on fertilization system the average values of partial nutrient balance of phosphorus in grain + straw and grain for all studied period decreased with increasing rate of applied phosphorus both in systems with alone phosphorus fertilization and in those included N_{120}. From the obtained results in the present study was established, that phosphorus was used inefficiently. Partial nutrient balance of phosphorus indicated, that the most stable fertilization system was $N_{120}P_{80}$, and the most unstable was the system in alone phosphorus fertilization 160 kg.ha^{-1} (Tab 4).

The highest average values were obtained in fertilization system $N_{120}P_{80}$ – 0.86 kg.kg^{-1} for grain + straw and 0.49 kg.kg^{-1} for grain, as proven exceed with

100% for grain + straw and 104% for grain those in the system with the same phosphorus rate, but with excluded nitrogen and proven exceed the values shown in all other systems. The lowest values of the indicator partial nutrient balance were in the systems with alone phosphorus fertilization 160 kg.ha^{-1} and were less by 244% for grain + straw and 277% grain compared to the combined system $N_{120}P_{80}$. Higher values of partial nutrient balance of phosphorus in combined nitrogen-phosphorus fertilization systems due to the effect of nitrogen on the mobilization and utilization of more phosphorus by plants from soil reserves.

Table 4. Partial nutrient balance (PNB) of phosphorus for grain+straw and grain (kg P_2O_5/kg) depends on the fertilization system in cultivar Progress

A. Fertilization system	2011	2012	2013	Average for the period
Partial nutrient balance of phosphorus for grain+straw				
N_0P_{80}	0.35	0.58	0.37	0.43 cd
N_0P_{120}	0.26	0.43	0.33	0.34 cd
N_0P_{160}	0.22	0.29	0.22	0.25 d
$N_{120}P_{80}$	1.0	0.87	0.71	0.86 a
$N_{120}P_{120}$	0.73	0.65	0.52	0.63 b
$N_{120}P_{160}$	0.58	0.49	0.38	0.48 bc
B. Year	0.52 ns	0.55	0.42	
Partial nutrient balance of phosphorus for grain				
N_0P_{80}	0.20	0.31	0.21	0.24 c
N_0P_{120}	0.15	0.23	0.18	0.19 cd
N_0P_{160}	0.12	0.15	0.12	0.13 d
$N_{120}P_{80}$	0.58	0.47	0.40	0.49 a
$N_{120}P_{120}$	0.41	0.35	0.30	0.35 b
$N_{120}P_{160}$	0.33	0.25	0.22	0.26 bc
B. Year	0.30 ns	0.29	0.24	

In a study of various fertilization systems of durum wheat cultivar Progress was established proven differences in physiological efficiency of phosphorus for grain and grain protein depends on the fertilization system. Average values for the studied period obtained in the combined nitrogen-phosphorus fertilization were proven higher than those in the system with excluded nitrogen and were in range 38.8 – 47.9 kg.kg^{-1} for grain and 6.2 – 7.8 kg.kg^{-1} for grain protein, and in the alone phosphorus fertilization the physiological efficiency was significantly lower, respectively the values for grain were 14.9 – 24.1 kg.kg^{-1} and for grain protein 1.9 – 3.3 kg.kg^{-1}.

The highest values of the physiological efficiency of phosphorus were obtained in fertilization system $N_{120}P_{80}$ – 47.9 kg.kg^{-1} for grain and 7.8 kg.kg^{-1} for grain protein, as proven exceed those in alone phosphorus fertilization 160 kg.ha^{-1} with 221 % for grain and 310% for grain protein. This significant difference is

indicative of the high effect of nitrogen on physiological efficiency of phosphorus for grain and grain protein.

The obtained higher values of physiological efficiency of phosphorus in the systems with nitrogen fertilization 120 kg.ha^{-1} due to the effect of nitrogen to formation a higher additional yield grain and grain protein (Tab. 5)

Table 5. Physiological efficiency (PE) of phosphorus for grain and grain protein (kg P_2O_5/kg) depends on the fertilization system in cultivar Progress

A. Fertilization system	2011	2012	2013	Average for the period
Physiological efficiency of phosphorus for grain				
N_0P_{80}	6.0	21.7	18.5	15.4 b
N_0P_{120}	17.9	23.5	30.8	24.1 b
N_0P_{160}	17.1	8.3	19.3	14.9 b
$N_{120}P_{80}$	53.3	42.1	48.2	47.9 a
$N_{120}P_{120}$	49.8	38.7	45.8	44.8 a
$N_{120}P_{160}$	44.5	33.5	38.6	38.8 a
B. Year	31,4 ns	28.0	33.5	
Physiological efficiency of phosphorus for grain protein				
N_0P_{80}	1.08	2.99	2.52	2.2 c
N_0P_{120}	2.52	3.29	4.05	3.3 c
N_0P_{160}	2.20	1.16	2.32	1.9 c
$N_{120}P_{80}$	8.55	7.05	7.88	7.8 a
$N_{120}P_{120}$	8.26	6.83	7.88	7.7 a
$N_{120}P_{160}$	6.96	5.49	6.26	6.2 b
B. Year	4.93 ns	4.47	5.15	

CONCLUSIONS

The partial factor productivity of phosphorus changed from 13.4 to 51.8 kg grain per kg P_2O_5 applied in dependence of the fertilizing system. The average agronomic efficiency was varied in range 1.6-28.1 kg grain and 0.20-4.58 kg grain protein for the experimental period.

Apparent crop recovery efficiency of applied phosphorus (kg increase in P uptake per kg P applied) was very low 0.11-0.15 kg.kg^{-1} when wheat was grown with no nitrogen fertilization. Recovery efficiency and physiological efficiency of applied P (kg yield increase per kg increase in P uptake from fertilizer) did not depend of the quantity of applied phosphorus P_{80}-P_{160} in systems without nitrogen.

Alone phosphorus fertilizing in rates 80-160 kg P_2O_5.ha^{-1} demonstrated lower efficiency of phosphorus expressed as calculated indicators partial factor productivity, agronomic efficiency, apparent crop recovery, partial nutrient balance, and physiological efficiency. Systematic fertilization of durum wheat in rates $N_{120}P_{80}$ was the most effective in average for the experimental period.

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