Effect of phosphoric fertilizers as a source of sulphur on malt barley total and technological grain yields

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ABSTRACT

Malt barley production requires a technology increasing nitrogen use efficiency, because of a high sensitivity of barley total grain yield and quality parameters to external growth factors. In the conducted study an effect of two P fertilizers on the background of N application on total and technological grain yields were studied. The highest total grain yield was harvested on plots fertilized with 60 kg N/ha, irrespective of the P fertilizer type. However, the technological grain yield showed a high year-to-year variability; the highest was recorded in 2001 on the plot fertilized with 60 kg N/ha and the P-PAPR fertilizer. The N and S concentrations and N:S ratios in immature grains at harvest were used to evaluate both yield types. Nitrogen concentration in the final total yield allowed making yields prognosis with the highest probability. The maximum yields of technological malt barley were attainable provided that total S concentration in immature grains at harvest was above 0.23% and the N:S ratio was narrower than 8.0.

Keywords: malt barley; maturity; immature grain fraction; nitrogen and sulphur indices; grain yields

Malt barley is crop of a very high economic risk for farmers, due to its high sensitivity to external growth factors; the latter are responsible for two physiological traits, namely the rate of canopy growth and nitrogen economy. Both characteristics affect main grain yield components, i.e. number of grains per ha and their individual weight (Papastylianou 1995, Pecio 2002).

The main farmers' instrumentation to meet quality parameters of cultivated malt barley is to decrease the amount of applied N fertilizer. However, this strategy does not allow to produce high yields of grain (Conry 1997). Thus, the economically sound system of malt barley cultivation may be supported by three pillars:

(a) a choice of a covariety showing high resistance to the variability of external factors,
(b) an optimization of the nitrogen fertilizer rate,
(c) an optimization of the physiological use efficiency of N taken up by plants.

Cereals are frequently classified as a group of crops with moderate P but low S requirements. Those requirements can be met by using most phosphoric fertilizers, which are physical carriers of following three nutrients: phosphorus, sulphur and calcium (Gassner and Grzebisz 2003, Potarzycki 2003).

The main objective of this study was to assess the effect of phosphoric fertilizers on the background of N fertilization on malt barley total and technological yields. The minor objective was to check the applicability of some N, S and N:S indices as reliable estimators of both types of grain yields.

MATERIAL AND METHODS

Field experiments were conducted in three consecutive growing seasons, 2001, 2002 and 2003, in Sielinko (Poland; 52.40°N, 16.90°E). Soils in the experimental site are loamy sands and are classified as Albic Luvisols (LVa) according to FAO. Details on agrochemical characteristics of soils at experimental plots are reported in Table 1.

Two factorial experiments consisted of:

(1) two types of P fertilizers: (a) NK, (b) NPK; P as SSP (single superphosphate), (c) NPK; P as PAPR (partially acidulated phosphate rocks, containing 70% of water soluble P);
(2) two levels of applied N: 0 and 60 kg/ha.

All treatments were replicated 4 times in a randomized block design.

The covariety Brenda, following white mustard in rotation, was sown at the end of March (3/III).

Table 1. Agrochemical properties of soils in the experiment plots

Agrochemical properties	Year		
	2001	2002	2003
pH (1M KCl)	7.1	6.7	6.5
Organic carbon (g/kg)[I]	14.5	15.5	11.0
Mineral nitrogen (kg N/ha)[II]	58.6	49.2	52.6
Available phosphorus (mg P/kg)[III]	80	75	66
Available potassium (mg K/kg)[III]	124	112	100
Available magnesium (mg Mg/kg)[IV]	64	66	55
Sulphate (mg $S-SO_4$/kg)[V]	2	8	10

[I]Tiurin method; [II]0.01M $CaCl_2$ 0–60 cm; [III]Egner-Riehm method; [IV]Schachtschabel method; [V]Bardsley-Lancaster method

All fertilizers were applied in spring, just before barley sowing. Rates of incorporated nutrients were as follows:

(a) phosphorus (P) – 37 kg/ha as SSP or PAPR;
(b) sulphur (S) – 25 kg/ha as a component of P fertilizers;
(c) potassium (K) – 100 kg/ha as KCl;
(d) nitrogen (N) – 60 kg/ha as ammonium nitrate (34%).

Herbicides and all other agro-technologies were applied according to standard practices.

At maturity (1/VIII), crops were harvested from the area of 12 m^2 using a plot combine-harvester. Total grain yields were adjusted to 14% moisture content. Technological grain yields were calculated by subtracting from the total grain yield a grain fraction passing 2.5 mm sieve and all other fractions containing more than 1.84% of total N. The concentration of total N was determined for each grain fraction and other organs, separately, using the Kjeldahl method (Kjeltec Auto Distillation). Sulphur (S) determination in plant samples was made according to the Bardsley-Lancaster method (Bardsley and Lancaster 1960).

In the experiment, three main grain characteristics of malt barley plants were investigated:

(a) grain total yield, GTY;
(b) total N, S concentrations, N_T, S_T (%, dm);
(c) grain N, S contents (kg/ha).

The following set of indices describing nitrogen use efficiency were applied:

(a) agronomic efficiency: $AE = [(TGY_f - TGY_{uf})/60]$;
(b) N recovery: $R = \{[(N_{Tf} - N_{Tuf})/60] \times 100\%\}$;
(c) physiological efficiency: $PhE = [(N_{Tf} - N_{Tuf})/(TGY_f - TGY_{uf})]$;
(d) specific nitrogen uptake: $SNU = N_T/TGY$;
(e) specific sulphur uptake: $SSU = S_T/TGY$.

The indices of N use efficiency were discriminated for N treatments: fertilized (f) and unfertilized (uf).

The experimentally obtained data were subjected to conventional analysis of variance. Least significant difference values (LSD at $P = 0.05$) were calculated to establish the significance of mean differences. The Cate-Nelson graphical procedure was applied to evaluate the critical concentration of S and the N:S ratio in barley plants (Nelson and Anderson 1977). The path analysis was applied to assess interrelationships between barley grain yield and its yielding components (Konys and Wiśniewski 1984).

RESULTS AND DISCUSSION

Characteristics of grain yields

Malt barley plants growth during vegetation is highly affected by water availability and temperatures. During our study, distribution of precipitations over growing seasons was highly variable. In 2001, the amount of rainfall and its distribution was supra-optimal for barley plants; in following years (2002 and 2003) it was highly unfavorable. In the 2002 growing season, the deficit of precipitations was mild, in 2003 extremely deep. In addition, the lack of precipitation was combined with an increase of the average monthly tempera-

Table 2. Effect of phosphoric fertilizers and N application on total grain yield of malt barley, means for 2001–2003 (t/ha)

Nitrogen rates [A] (kg N/ha)	Phosphoric fertilizers [B]			Mean for A
	NK 0 P	NPK SSP[1]	NPK PAPR[2]	
0	2.90	3.24	3.38	3.175
60	3.58	4.30	4.29	4.044
$LSD_{0.05}$		0.2277		–
Mean for B	3.220	3.773	3.837	
$LSD_{0.01}$		0.1610		0.1314

[1]single superphosphate; [2]partially acidulated phosphate rocks

Table 3. Effect of phosphoric fertilizers on nitrogen use efficiency, means for 2001–2003

P treatments	AE[1] (kg/kg N)	R (%)	PhE (kg/kg N)	SNU (kg/t)	SSU (kg/t)
0	10.6	38.4	27.5	24.2	5.2
SSP	17.6	49.8	35.0	21.4	4.8
PAPR	15.2	42.9	34.9	22.4	5.4
$LSD_{0.05}$	n.s.	10.30	n.s.	2.05	n.s.

[1]described in the text

tures of about 2–3°C in comparison to the long-term averages. It is well recognized that these two meteorological traits are highly unfavorable for both, total grain yield of malt barley and its technological quality (Papastylianou 1995, Savin and Nicolas 1996).

Total grain yields of malt barley were significantly affected by both experimental factors, irrespective of the great weather variability (Table 2). The highest yields, amounting to about 4.3 t/ha, were harvested on plots fertilized with 60 kg N/ha and with P, irrespective of the P fertilizer type. The lowest yield, amounting to 2.9 t/ha, was obtained on the NK plot. Effects of fertilizer phosphorus were quite conspicuous. Plants grown on the plots without added N, averaged over P treatments, increased total grain yield by 0.4 t/ha, while those fertilized with N by 0.7 t/ha. These two figures clearly corroborate the significant effect of N and P shortages and physiological impact on yield of malt barley (Prystupa et al. 2003). However, the main parameter of N efficiency, i.e. agronomic efficiency (AE), showed no response to P fertilization, mainly due to high seasonal variability. However, the observed effects are quite high, because SSP fertilizer increased AE by 66% and PAPR by 43% (Table 3).

The effect of N fertilization on barley total grain yield and its component structure is well known and has been confirmed in the present study. However, the effect of P is controversial, as found for wheat (Rodriquez et al. 1999). Based on the analysis of path coefficients, established for yield and its yield components, it was found, including all nitrogen fertilized treatments, that in the case of the P control (NP treatments) and SSP, total grain yield was in the first case affected by the number of grains per ear, which indirectly depended on the number of ear-bearing stems (Figure 1). In the case of PAPR treatments, the recorded grain yield was determined mainly by the number of ears. It should be also pointed out that under conditions of phosphorus deficiency, the relationship between grain yield and TGW was negative.

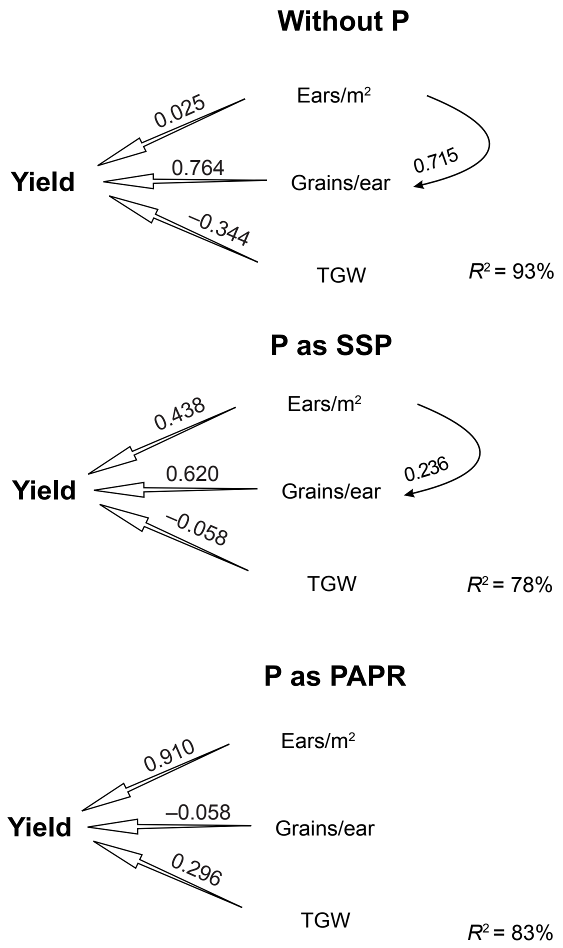

Figure 1. Path analysis coefficients between yield of malt barley and yield structure components (n = 12)

Table 4. Effect of phosphoric fertilizers and nitrogen application on technological grain yield of malt barley (t/ha)

Year	Nitrogen rates [A] (kg N/ha)	Phosphoric fertilizers [B] NK 0 P	NPK SSP[1]	NPK PAPR[1]	Mean for A × years
2001	0	2.950	3.405	3.583	3.313
	60	3.665	3.500	4.780	3.982
2002	0	2.633	2.883	3.085	2.867
	60	3.185	3.963	3.740	3.629
2003	0	2.305	2.740	2.708	2.584
	60	2.458	3.365	3.223	3.015
$LSD_{0.01}$		0.3611			0.2085

[1]described in the Table 2

Table 5. Effect of phosphoric fertilizers and nitrogen application on nitrogen concentration in barley vegetative organs at maturity, means for 2001–2003 (% dm)

Plant organs	Nitrogen rates [A] (kg N/ha)	Phosphoric fertilizers [B]			Mean for [A]	LSD $NIR_{0.05}$ for plant organs
		NK 0 P	NPK SSP[1]	NPK PAPR[1]		
Leaves	0	0.69	0.64	0.62	0.65	0.115
	60	0.74	0.74	0.89	0.79	
Stems	0	0.36	0.30	0.40	0.35	n.s.
	60	0.44	0.39	0.42	0.42	
Chaffs	0	0.50	0.53	0.48	0.50	0.055
	60	0.65	0.62	0.68	0.65	

[1]described in the Table 2

The calculated technological grain yields of malt barley were affected by experimental factors but showed a significant year-to-year variability (Table 4). The highest yield, amounting to 4.78 t/ha was harvested in 2001 on the plot fertilized with PAPR and 60 kg N/ha; the lowest yield, of about 2.4 t/ha, was harvested in 2003 on NK plots. Grain yields were significantly affected by the interaction of N and P fertilizers and year. In 2001 the most significant effect was found for PAPR but in the other two years no significant differences between tested P fertilizers were observed. The highest relative yield increase due to the N and P interaction was 62% in 2001, 42% in 2002 and 40% in 2003. Effects of P application without N were much lower, still they amounted to 21%, 17% and 21%, respectively.

Nitrogen and sulphur concentrations in barley organs at maturity

Total and technological grain yields of malt barley are highly sensitive to soil nitrogen availability (Conry 1997). However, its quantitative and qualitative effects depend on plant nutritional homeostasis, for example sulphur availability during grain filling period. Therefore, nitrogen and sulphur concentrations and contents at maturity were used to predict both types of yields.

At maturity, nitrogen concentrations in barley vegetative organs showed a high year-to-year variability, especially for chaffs and leaves (Table 5). Despite the seasonal weather variability, these two organs significantly responded to N application. Sulphur concentrations in barley vegetative organs showed only a year-to-year variability as presented in Table 6 for leaves. However, the calculated correlations between N or S concentrations in all studied vegetative organs and total grain yields and/or technological yields were generally low and mostly insignificant.

Basic qualitative parameters of malt barley consisted of (i) grain fraction left after sieving total grain yield on the 2.5 mm sieve (ii) fractions of N concentration below 1.84% in screenings grain. All fractions out of these rules represent the lost pool of total malt barley grain yield. Therefore, it was assumed, that N and S concentrations in grain fraction passing the 2.5 mm sieve, are of a great value for the technological yield and its qualitative estimation.

Table 6. Effect of phosphoric fertilizers and nitrogen application on sulphur concentration in leaves of malt barley at maturity (% dm)

Year	Nitrogen rates [A] (kg N/ha)	Phosphoric fertilizers [B]			Mean for A × years
		NK 0 P	NPK SSP[1]	NPK PAPR[1]	
2001	0	0.37	0.35	0.36	0.36
	60	0.36	0.35	0.35	0.35
2002	0	0.27	0.23	0.31	0.27
	60	0.22	0.26	0.26	0.25
2003	0	0.15	0.16	0.15	0.16
	60	0.15	0.13	0.20	0.16
Mean for [B]		0.25	0.25	0.27	–

[1]described in the Table 2

Table 7. Effect of phosphoric fertilizers and N application on N and S concentrations in malt barley grain, fraction < 2.5 mm

Year	Nitrogen rates [A] (kg N/ha)	Phosphoric fertilizers [B]			Mean for A × years
		NK 0 P N^2/S^3	NPK SSP[1] N/S	NPK PAPR[1] N/S	
2001	0	1.62/0.27	1.91/0.28	1.86/0.27	1.80/0.27
	60	1.79/0.27	2.07/0.29	2.04/0.29	1.97/0.28
2002	0	1.50/0.17	1.75/0.21	1.59/0.17	1.61/0.19
	60	1.77/0.21	1.89/0.24	1.98/0.23	1.88/0.23
2003	0	1.40/0.15	1.25/0.12	1.44/0.12	1.36/0.13
	60	1.66/0.13	1.67/0.21	1.68/0.20	1.67/0.18

[1]described in the Table 2; [2]N concentration, % dm; [3]S concentration, % dm

It was found that concentrations of N and S in immature grains responded to imposed experimental treatments, especially to N application, but weather variability was the most important factor (Table 7). These two data sets plus the calculated N:S ratios were used to assess the dependence of malt barley grain yields on N, S and N:S. The obtained relationships followed the linear regression model as presented below:

(a) N concentration

$Y_{TGY} = 0.59x - 0.22$; $R^2 = 0.72$; $n = 18$

$Y_{TeGY} = 0.54x - 0.099$; $R^2 = 0.63$; $n = 18$

(b) S concentration

$Y_{TGY} = 2.01x + 0.37$; $R^2 = 0.60$; $n = 18$

$Y_{TeGY} = 1.89x + 0.417$; $R^2 = 0.57$; $n = 18$

(c) N:S

$Y_{TGY} = -0.05x + 1.21$; $R^2 = 0.34$; $n = 18$

$Y_{TeGY} = -0.049x + 1.2332$; $R^2 = 0.36$; $n = 18$

where: x – N (% dm); S (% dm), N:S ratio in the grain fraction below 2.5 mm, respectively; Y_{TGY}, Y_{TeGY} – total and technological yields of malt barley grain, respectively

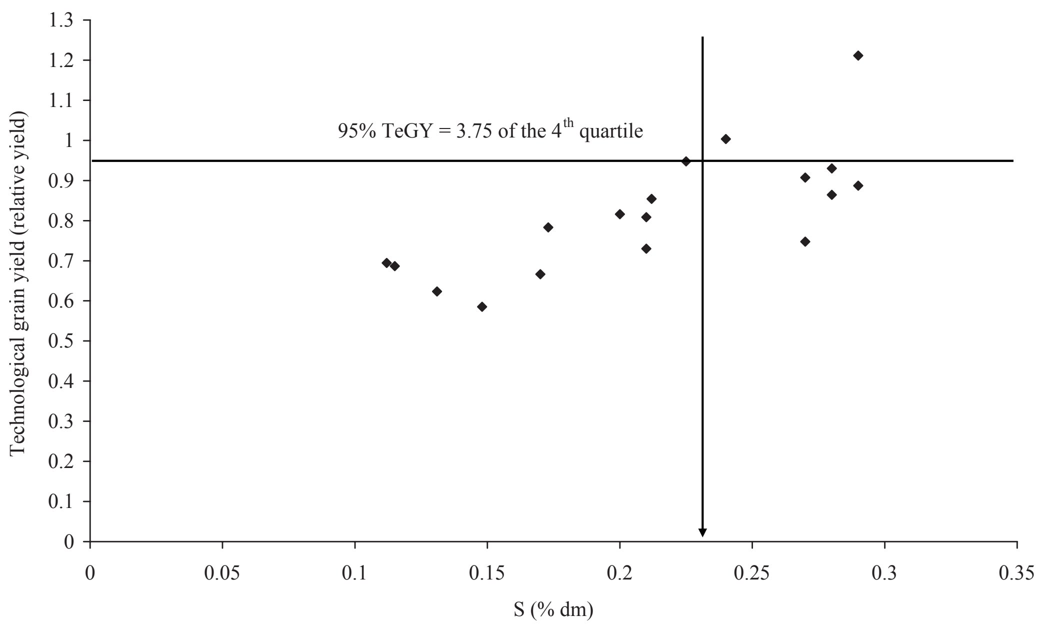

Figure 2. The scatter diagram of the technological grain yield of malt barley versus S concentration in the grain fraction < 2.5 mm

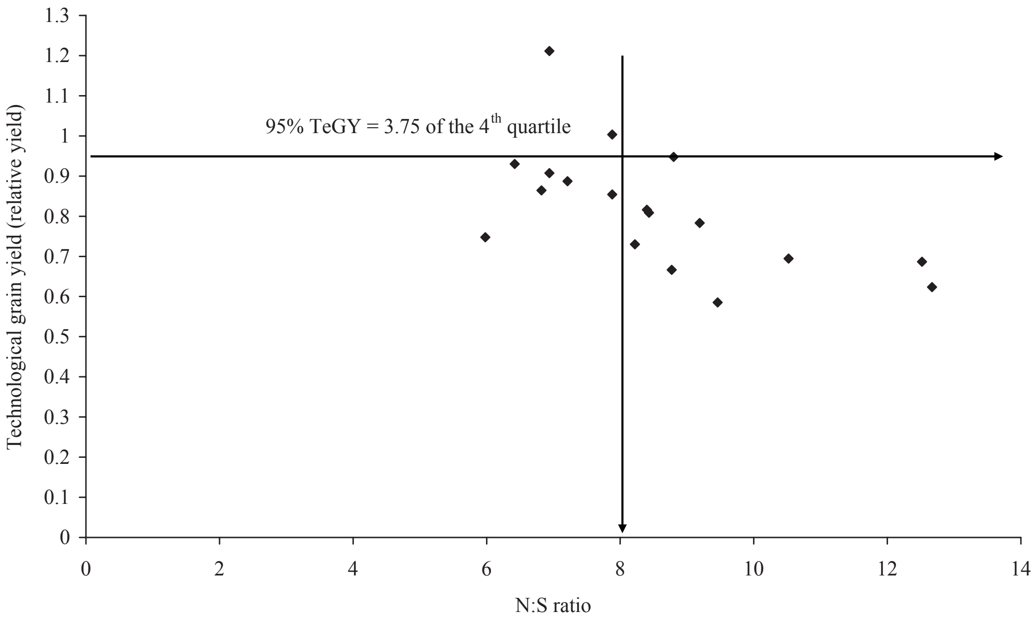

Figure 3. The scatter diagram of technological grain yield of malt barley versus the N:S ratio in the grain fraction < 2.5 mm

The highest values of coefficients of determination were found, as expected, for N concentration in immature grains. Both presented equations show that the higher amount of nitrogen in immature grains is, the higher yields are expected. This statement arises a question about the role of phosphoric fertilizers as a source of S; the critical values of the S concentration and the N:S ratio in this particular pool of barley technological yield needs to be established urgently. However, all the above-presented linear equations are not practically useable. Thus, the Cate-Nelson procedure was applied to delimitate the critical value of each of these two parameters of the technological bar-

Table 8. Effect of phosphoric fertilizers and nitrogen application on total nitrogen and sulphur uptake by malt barley plants at maturity, means for 2001–2003

Nitrogen rates [A] (kg N/ha)	Phosphoric fertilizers [B]			Mean for A
	NK 0 P	NPK SSP[1]	NPK PAPR[1]	
Nitrogen uptake (kg N/ha)				
0	66.2	66.4	72.7	68.4
60	89.2	96.3	98.5	94.7
$LSD_{0.05}$		–		2.94
Mean for B	77.7	81.4	85.6	–
$LSD_{0.05}$		3.60		–
Sulphur uptake (kg S/ha)				
0	15.3	15.9	18.7	16.6
60	18.9	20.8	23.9	21.2
$LSD_{0.05}$		–		2.2
Mean for B	17.1	18.3	21.3	–
$LSD_{0.01}$		2.68		–

[1]described in the Table 2

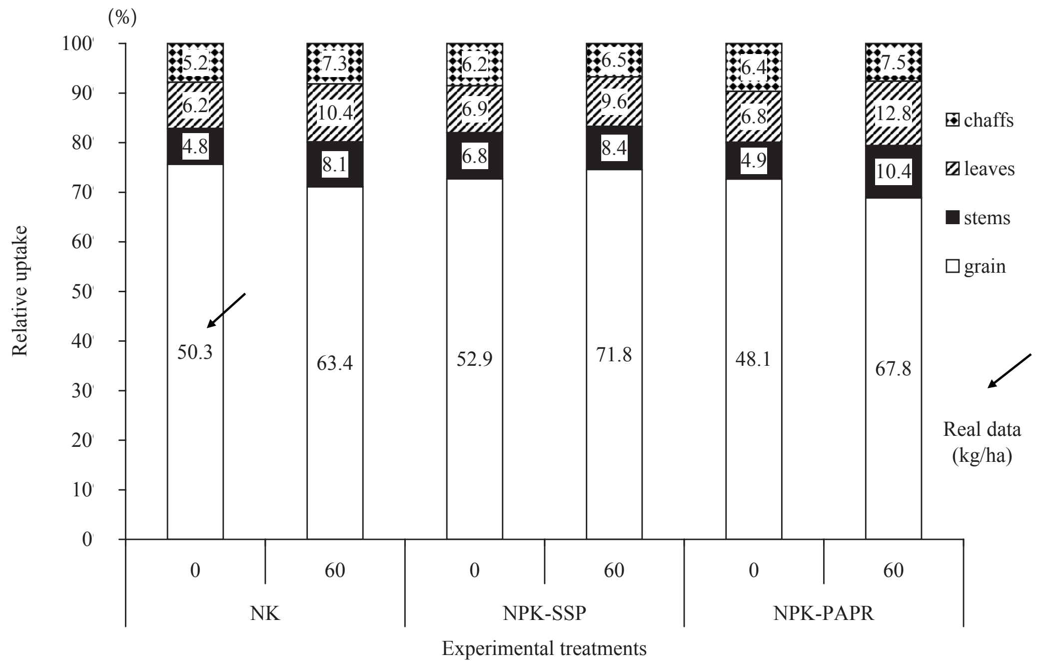

Figure 4. Effect of phosphoric fertilizers and nitrogen application on relative distribution of accumulated nitrogen among malt barley organs at maturity

ley grain yield. The obtained results are shown in Figures 2 and 3, respectively. With respect to S concentration, its critical values above 0.23% in the grain fraction below 2.5 mm allow to reach the potential yield of 3.75 t/ha and the calculated critical N:S ratio for potential yield is 7.5.

Nitrogen and sulphur accumulation in plants at maturity

Values of nitrogen and/or sulphur uptake can be used as useful indices of malt barley yield and quality. In spite of a high seasonal variability, amounts of

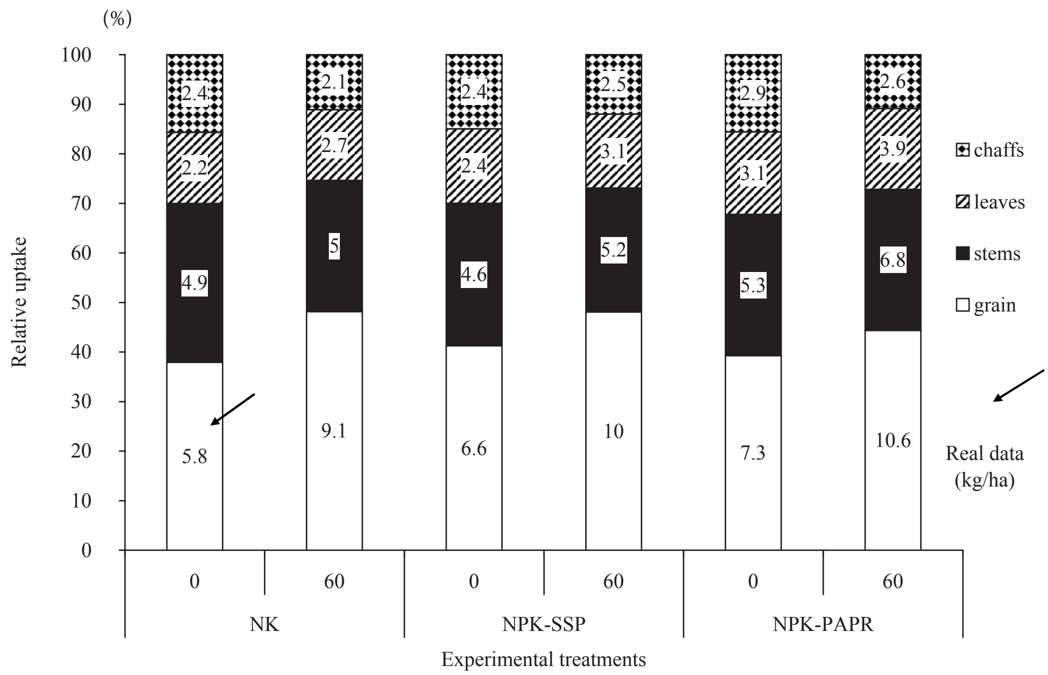

Figure 5. Effect of phosphoric fertilizers and nitrogen application on relative distribution of accumulated sulphur among malt barley organs at maturity

accumulated nutrients showed a significant effect of experimental factors (Table 8). Nitrogen uptake, averaged over P treatments, increased by 10%. The effect of P fertilizers showed no interaction with N application but significantly increased N uptake following the order: control < SSP ≤ PAPR. The structure of N accumulation and its distribution among malt barley organs averaged over years generally shows a very similar pattern for all studied treatments (Figure 4). The calculated nitrogen harvest indexes (NHI) based on N uptake were high, ranging from 69% to 76%. The N recovery was generally low, below 50%, but increased in an ascending order: control (38%) ≤ PAPR (43%) ≤ SSP (48%) (Table 3).

Sulphur accumulation by barley plants at maturity also responded to both experimental factors (Table 8). Plants fertilized with nitrogen, averaged over phosphorus treatments and years, increased S uptake by 28%. In comparison to the NK plot, only PAPR as P fertilizers significantly increased S uptake by barley plants. The structure of S accumulation and distribution among barley plants organs was quite different in comparison to nitrogen (Figure 5). In general, S accumulation in barley organs followed the order: grain > stems > leaves > chaffs. For the last two organs, the presented order was valid only for plants grown on plots fertilized with N. Plants, which were not fertilized with N showed almost equal amounts of S in these two organs. The sulphur harvest index (SHI) ranges from about 40% for all N–0 treatments to more than 45% for NPK plots. This data set clearly stresses a significant effect of N application on total S accumulation and distribution among organs of barley plants.

Two useful practical indices, specific nitrogen uptake (SNU) and specific sulphur uptake (SSU), sum up the effect of the tested P fertilizers on barley nutrient economy (Table 3). The first index shows a significant decrease in response to P application by 7.5% for PAPR and by 11.5% for SSP. For the second one, slightly lower values were calculated for SSP, but no significant response was found.

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