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Teresa Oracka, Jan Ciepły, Janusz Kozdój

Plant Breeding and Acclimatization Institute, Radzików, 05-870 Błonie, Poland

GENETIC VARIABILITY IN N, P, K UTILIZATION EFFICIENCY IN SPRING WHEAT AT DIFFERENT CONCENTRATION OF NUTRIENT SOLUTIONS

ABSTRACT

From the ecological and economic points of view it is necessary to change agricultural practice towards low- input cultivation systems. This requires breeding of new cultivars with improved utilization efficiency of mineral nutrients. The response of fifty spring wheat cultivars representing different origin and years of release (from 1990 to 1996) to different concentrations of the Hoagland nutrient solution was investigated under controlled conditions (climatic chamber).

A wide variability in N, P, K contents, their utilization efficiency and production of dry matter was found among wheat cultivars at the shooting phase of plant development at all nutrient concentrations applied. The variability coefficient decreased with the increasing concentration of Hoagland solution.

Old Polish cultivars (released 1900 – 1960) and most of the intermediate cultivars (released 1961 – 1980) showed high of N, P, K utilization efficiency. The modern cultivars (released after 1981) showed either high or low N, P, K utilization efficiency. This efficiency was determined by dry matter (r= 0.94 - 0.98) and N, P, K contents (r= 0.62 - 0.94). The majority of spring wheat cultivars showed almost linear response of the evaluated parameters to increased nutrient concentration in Hoagland solution.

It was been proved that genetic variability of N, P, K utilization efficiency can be assessed as early as at shooting phase.

Key words: Spring wheat, genetic variability, nitrogen, phosphorus, potassium utilization efficiency.

INTRODUCTION

Breeding has been very successful in generating cultivars which increased agricultural production even several fold in highly favourable environments, by fertilizers and chemical control of weeds, pests and disease. At present the environmental impact of high input agriculture in more favourable environments causes a growing ecological concern (Ceccarelli 1994). The new European Common Agricultural Policy and environmental considerations confirm that the agricultural practice should be changed toward a low input cultivation system (Le Gouis and

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Pluchard 1996). It requires breeding of new cultivars with improved efficiency of nutrients use. This breeding direction requires a recognition of: i) a genetic variation of the traits related to the utilization efficiency of nutrients, ii) the response to different level of nutrients, iii) variation of those traits during vegetation and its relation to the yield.

In this study the genetic variation in nutrient utilization and a response of fifty spring wheat cultivars to different concentrations of nutrient were investigated under controlled conditions (climatic chamber).

MATERIALS AND METHODS

Fifty spring wheat cultivars representing different years of release (from 1990 to 1996) derived from different countries were investigated (Table 1). The source of information about yield of these cultivars were from: the Research Centre for Cultivar Testing and the El Bassam (1998) and our unpublished data.

Plants were grown in plastic tanks containing 40 l of the modified Hoagland no.2 solution (Batten, 1986) at the concentrations of macro and micro nutrients given in Table 2

The nutrient solution was renewed every 4 day and aerated for 10 min every hour. To verify a plant response to further increase of nutrient concentration, 23 cultivars were grown comparatively at the standard and high concentration. The experimental set up was based on the randomized complete block design with a factorial combination of the four fertility levels, 50 genotypes and 3 replications.

The experiments were carried out in a growth chamber under the conditions given in Table 3

Light in a growth chamber was provided by metal halide lamps (NACHROMA, type NCE -1000W).

At the shooting phase, seven plants in 3 replicates of each cultivar were harvested. Leaves, stems and roots were separated and their dry matter (105°C) was recorded.

Standard procedures (Kjeldahl digestion, ammonium molibdate photometry and flame photometry) were used to determine N, P, K concentration in dry matter. From this data the N, P, K contents and utilization efficiency (the plant biomass/ N, P, K tissue concentration [$mg^2 \times mg^{-1}$]) -according to Siddigi and Glass 1983) was calculated. Data were processed by the analysis of variance. Differences were tested by the Tukey's test.

Table 1

Plant height and grain yield of 50 spring wheat cultivars

No.	Name of cultivar	Country of origin	Plant height	Grain yield	Year of release
46	Ostka Łopuska	PL	9	3	old
45	Kalinowiecka	PL	9	3	old
47	Ostka Suska	PL	9	3	old
44	Gorzowska Wczesna	PL	7	1	old
43	Gorzowska Sztywna	PL	9	3	old
48	Urbanka	PL	7	3	inter
22	Kolibri	D	7	4;5	inter
31	Rubino	B	3	5	inter
35	Sappo	S	6	5	inter
42	Alfa	PL	6	6	inter
49	Jara	CZ	6; 7	5	inter
20	Kenya Leopard	KE	5	4	mod
21	Kenya Tembo	KE	5	4	mod
41	Turbo	D	5	5	mod
1	Achil	D	3	5	mod
29	Ralle	D	6	8;9	mod
4	Axona	NL	3	3	mod
37	Star	D	3	6	mod
28	Planet	D	5	8	mod
11	Eta	PL	5	6	mod
14	Henika	PL	5	5	mod
50	Sokrates	D	5	5	mod
26	Nemares	D	5	5	mod
36	Sigma	PL	3;4	6	mod
18	Jota	PL	3	6	mod
25	Nandu	D	5	9	mod
7	Broma	PL	3	9	mod
2	Alkora	PL	5	5	mod
8	Combi	D	5	4	mod
13	Hanno	D		5	mod
15	Hera	PL	3	5	mod
27	Omega	PL	5	7	mod
12	Filou	F	4	5	mod
24	Naxos	D	3	4	mod
3	Arcade	NL	3	3	mod

Table 1

Continued

No.	Name of cultivar	Country of origin	Plant height	Grain yield	Year of release
10	Devon	D	5	5	mod
16	Igna	PL	5	7	mod
23	Munk	D	3	4; 5	mod
30	Regulus	B	3	5	mod
33	Sampan	GB	1	4	mod
39	Tinos	D	4	6	mod
40	Troy	GB	3	3	mod
6	Banti	PL	5	9	mod
17	Jondolar	NL	5	5	mod
38	Thasos	D	5	6	mod
5	Baldus	NL			mod
9	Cadenza	GB	2	3	mod
19	Jasna	PL	4	7	mod
32	Santa	PL	4	7	mod
34	Sandra	HR	3	3	mod

Grades: 1 – very low, 3 – low, 5 – medium, 7 – high, 9 – very high, B- Belgium, CZ- Czech Republic, D- Germany, F- France, GB – Great Britain, HR- Croatia, KE- Kenya, NL- Netherlands, PL- Poland, S- Sweden, old-old cultivars from 1900 to 1960, inter – intermediate cultivars from 1961- 1980, mod – modern cultivars after 1981

Table 2

Concentration of macro and micro nutrients

	Level of nutrients in solution [mg × l^{-1}]			
Nutrients	Very low (0.1)	Low (0.5)	Standard (1.0)	High (2.0)
		Macro nutrients		
$Ca(NO_3)_2 \cdot 4H_2O$	95	475	950	1900
KNO_3	61	305	610	1220
$MgSO_4 \cdot 7H_2O$	49	245	490	980
$NH_4H_2PO_4$	12	60	120	240
		Micro nutrients		
H_2BO_3	0.286	1.43	2.86	5.72
$MnCl_2 \cdot 4H_2O$	0.181	0.905	1.81	3.62
$CuSO_4 \cdot 5H_2O$	0.008	0.04	0.08	0.16
$ZnSO_4 \cdot 7H_2O$	0.022	0.105	0.22	0.44
$Na_2MoO_4 \cdot 2H_2O$	0.009	0.045	0.09	0.18
EDTA Fe-Na	0.0014	0.007	0.014	0.028

Table 3

Conditions of the growing of plants

Days of plant growth	Temperature day/ night [°C]	Length of day/ night [h]	Irradiance [mmol × m^2 × s^{-1}]
1-19	15/10	16/8	350
20-29	20/15	16/8	350

RESULTS

The investigated cultivars of spring wheat showed significant variability in dry matter and N, P, K utilization efficiency at shooting phase of plant development at all concentrations (Table 4).

Table 4

Mean squares for variables measured in 50 genotypes.

Traits	Genotypes (G)	Fertilization (F)	G × F	Error
NUE	128.0*	6617*	23.7*	0.42*
PUE	4495*	51452*	682.5*	11.59*
KUE	48.5*	1614*	8.6*	0.16*
Nc	193.1*	13962*	40.9*	0.82*
Pc	7.3*	1413*	1.9*	0.038*
Kc	526.1*	51390*	119.4*	2.21*
CN	12.5*	1088*	4.1*	8.7×10^{-3}*
CP	4.3*	487*	0.489*	3.5×10^{-3}*
CK	40.6*	5687*	15.5*	5.46×10^{-2}*
pDM	0.15*	9.4*	2.82×10^{-2}*	5.7×10^{-4}*
rDM	4.98×10^{-3}*	0.088*	1.3×10^{-3}*	5.2×10^{-5}*

N, P, K utilization efficiency (NUE, PUE, KUE), plant N, P, K content (Nc, Pc, Kc); plant concentration of N,P,K (CN, CP, CK); rDM – root dry matter; pDM – plant dry matter. * Significant at the 0,05 probability levels

Old tall Polish cultivars, especially Ostka Łopuska and Ostka Suska (bred 1900-1930), showed high N, P, K utilization efficiency. Also other old Polish cultivars: Gorzowska Wczesna, Gorzowska Sztywna and Kalinowiecka demonstrated rather high values of N, P, K utilization efficiency (Fig. 1). In the intermediate cultivars (released 1961-1980) Rubino, Alfa, Jara showed high utilization efficiency. The modern cultivars (released after 1981) demonstrated either high or low values of N, P, K utilization efficiency. High utilization was characteristic for Sokrates, Hera, Sampan cvs. while the lowest one was for Troy and Hanno cvs. The ranking of cultivars with regard of plant dry matter production was almost the same as for N, P, K utilization efficiency. The highest values showed Ostka Łopuska and Ostka Suska cvs. and the lowest Troy and Hanno cvs.

The N, P, K utilization efficiency was related with production of plant dry matter (r= 0.94 - 0.98) and N, P, K contents in total plant (r= 0.62 - 0.94). The correlation coefficients between utilization efficiency and N, P, K concentrations in dry matter of plant tissue were lower and negative (r= from -0.30 to -0.75). High efficiency of one nutrient element was highly correlated with the utilization efficiency of others (r= 0.95 – 0.98; Table 5).

Table 5

The correlation coefficients *r* between different parameters

Parameters	NUE	PUE	KUE	Nc	Pc	Kc	CN	CP	CK	pDM	rDM
NUE	1.00										
PUE	0.95	1.00									
KUE	0.98	0.95	1.00								
Nc	0.93	0.89	0.94	1.00							
Pc	0.79	0.62	0.79	0.89	1.00						
Kc	0.94	0.88	0.91	0.98	0.87	1.00					
CN	-0.48	-0.44	-0.40	NS	NS	NS	1.00				
CP	-0.57	-0.75	-0.55	-0.42	NS	-0.43	0.56	1.00			
CK	-0.30	-0.33	-0.41	NS	NS	NS	0.52	0.41	1.00		
pDM	0.98	0.94	0.98	0.98	0.85	0.97	-0.32	-0.51	NS	1.00	
rDM	0.79	0.69	0.82	0.90	0.92	0.86	NS	NS	NS	0.86	1.00

N, P, K utilization efficiency (NUE, PUE, KUE), plant N, P, K content (Nc, Pc, Kc); plant concentration of N,P,K (CN, CP, CK); rDM – root dry matter; pDM – plant dry matter. NS = non-significant

Table 6

The means and the maximum and minimum values of tested characteristics in 50 spring wheat cultivars at different level of nutrient solution

Parameters	Very low (0,1)			Low (0,5)			Standard (1,0)		
	mean	max	min	mean	max	min	mean	max	min
NUE	16,1	29,3	7,8	16,9	29,0	10,0	28,0	38,9	16,3
PUE	97,5	178,3	45,0	78,9	137,3	41,8	115,9	171,9	54,5
KUE	10,5	18,9	5,2	10,7	17,5	6,6	16,3	22,6	9,6
Nc	18,8	36,2	8,8	26,6	41,7	17,2	38	51,7	24,5
Pc	3,1	5,7	1,5	5,7	8,8	3,6	9,2	12,5	7,3
Kc	28,8	53,7	13,2	42,1	69,1	26,8	65,3	91,2	41,6
CN	34,3	39	29,5	39,7	42,9	37,8	36,9	39,3	32,4
CP	5,7	6,7	4,6	8,6	10,4	7,1	9,1	11,6	7,5
CK	52,6	58,5	45,7	62,9	69,6	58,8	63,6	70,1	56,8
pDM	0,549	1,007	0,263	0,669	1,1	0,428	1,03	1,418	0,632
rDM	0,135	0,232	0,066	0,138	0,224	0,079	0,178	0,241	0,128

N, P, K utilization efficiency (NUE, PUE, KUE), plant N, P, K content (Nc, Pc, Kc); plant concentration of N,P,K (CN, CP, CK); rDM – root dry matter; pDM – plant dry matter.

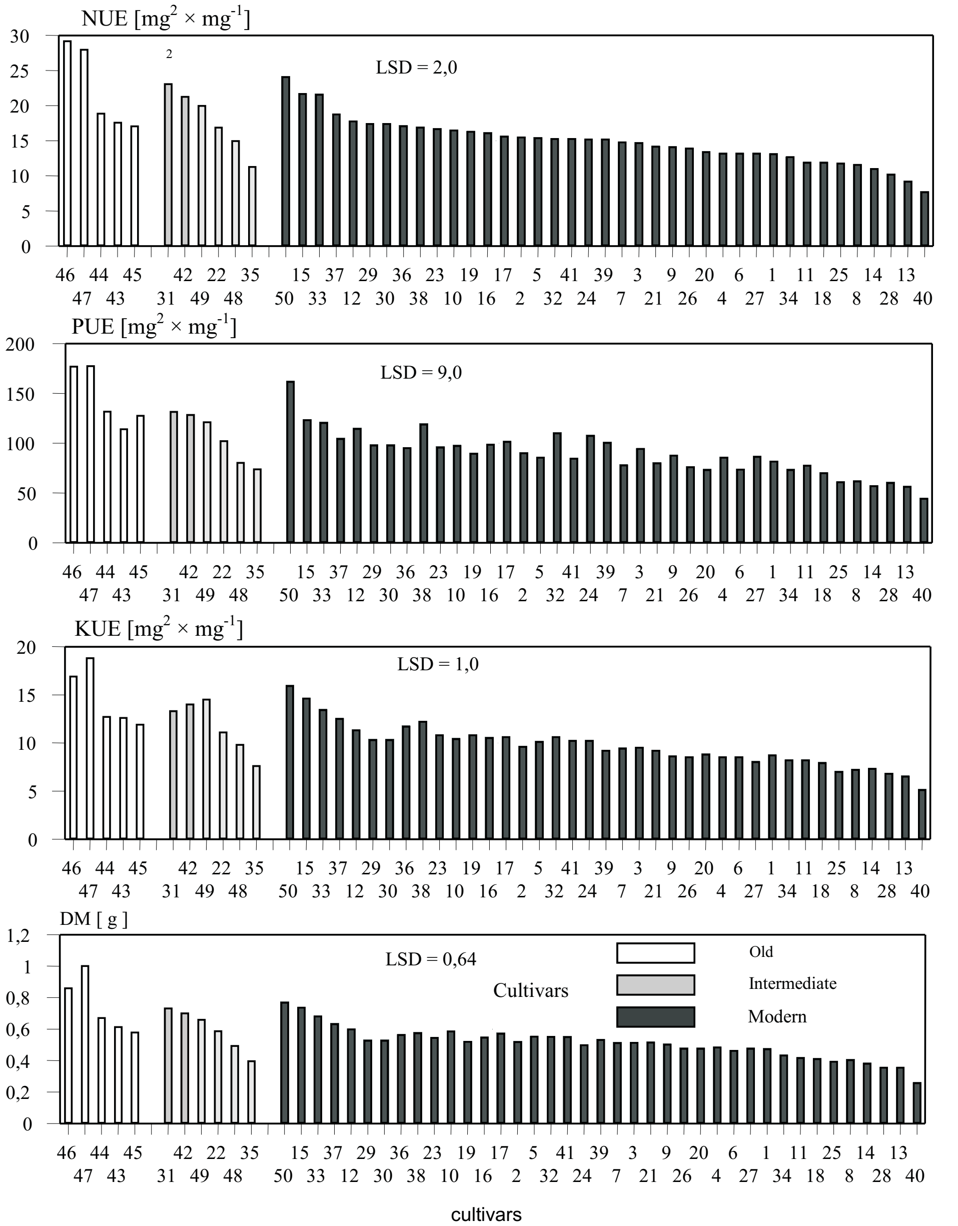


Fig. 1. Nitrogen (NUE), phosphorus (PUE), potassium (KUE) utilization efficiency and plant dry matter of 50 spring wheat cultivars at very low nutrient solution concentration.

Significant differences were noted in spring wheat genotypes between the nutrient level and the genotype x nutrient level interaction for N, P K utilization efficiency, N, P, K contents in whole plant and their concentration, plant and root dry matter (Table 4). Almost 3-fold differences appeared between the maximum and minimum values for N, P, K contents, utilization efficiency and dry matter (Table 6). Whereas for N, P, K concentrations these differences were evidently lower (by 30%). These differences were the most pronounced at a very low level of nutrient solution and decreased with its increasing concentration.

High variability of coefficients of N, P, K content, utilization efficiency and plant and root dry matter were observed. This coefficient decreased with the increasing of nutrient solution concentration (Fig. 2).

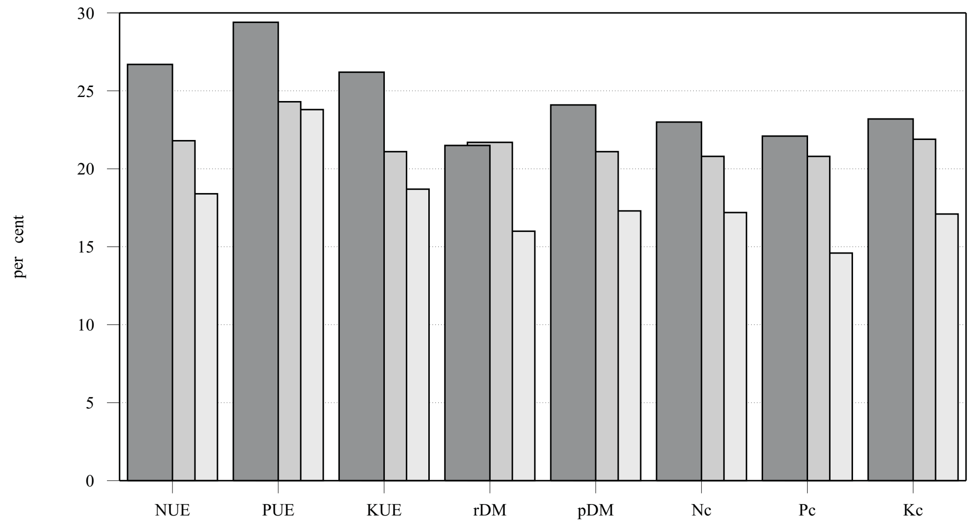
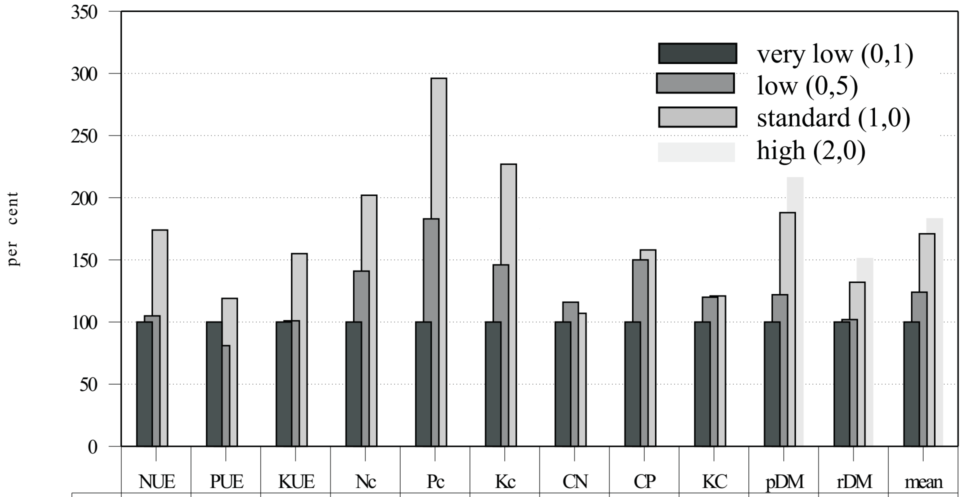


Fig. 2. The coefficient of variability of parameters at different nutrient solution concentration (denotations of traits as in Table 4)

The response of spring wheat plants (mean of the tested culivars) was significantly higher at increased concentration of nutrient solution (Fig. 3). For verification of this response, the response of 23 cultivars was compared at the standard and high level of Hoagland solution. A still higher increase of plant and root dry matter was found at high nutrient solution concentration.



	NUE	PUE	KUE	Nc	Pc	Kc	CN	CP	KC	pDM	rDM	mean
0,1	100	100	100	100	100	100	100	100	100	100	100	100
0,5	105	81	101	141	183	146	116	150	120	122	102	124
1	174	119	155	202	296	227	107	158	121	188	132	171
2										216	151	183

Fig. 3 Changes of tested characteristics (mean of 50 cultivars) at different levels of nutrient solution concentration (% in relation to very low - 0.1 level). N, P, K utilization efficiency (NUE, PUE, KUE), plant N, P, K content (Nc, Pc, Kc); plant concentration of N,P,K (CN, CP, CK); rDM – root dry matter; pDM – plant dry matter

The N, P K content increased linearly with the increasing concentration of nutrient solution from very low (0.1) to standard level (1.0), whereas N, P, K tissue concentration increased only up to the low level (0.5) of nutrient solution and the utilization efficiency increased only up to a standard level of the solution concentration.

The tested spring wheat cultivars showed a linear response of the evaluated parameters to increased concentration of nutrient solution.

DISCUSSION

Significant genotypic variation was observed for N, P, K utilization efficiency (plant biomass / tissue N, P, K concentration), N, P, K content in the whole plant and plant dry matter at the shooting phase of 50 spring wheat genotypes released from 1900 to 1996.

In many cereal species genetic variation in related to the nutrient utilization efficiency was established (Ciepły and Oracka 1990, 1992, 1994, 1996, Le Gouis and Pluchard 1996, El Bassam 1998, Siddigi and Glass 1983, Jones et al. 1992, Batten 1986, 1984, Van Sanford and Mac Kown 1986). Also a different response of plants to nutrient levels was shown

(Ciepły and Oracka 1994, Gerloff 1976). This offers a chance for selection of plants better adapted to different nutrition conditions.

The cofficient of variability of N, P, K content, utilization efficiency and plant dry matter were the highest at the lowest level of Hoagland solution and decreased with its increasing concentration. Ceccarelli (1996) indicated that the species and varieties adapted to favourable growing conditions are, in general, not well adapted to stress conditions. In consequence, the most efficient way to improve adaptation and yield in the low- input conditions is a direct selection in these particular conditions.

High N, P, K utilization efficiency and dry matter at the shooting phase were characteristic for old, tall and low yielding Polish cultivars and most of intermediate cultivars. Also some modern high yielding cultivars showed similar utilization efficiency. The old Polish cultivars bred in 1900-1930 when chemical fertilizers were not commonly used showed high biomass production through our the whole vegetation period and low yield because of lodging. Various studies proved that new cultivars produced higher grain yields than old ones, and are also more efficient in using nutrients (El Bassam 1998). Ortiz-Monasterio et al. (1997) concluded that with reduction of plant height grain yield and the harvest index increased, with simultaneously increased nutrient utilization efficiency. According to these authors a progress in improving utilization efficiency is due rather to harvest index than to biomass production. They suggested that breeding for increased grain yield could create an indirect selection pressure on utilization efficiency.

Our earlier results on nutrient utilization in new winter triticale genotypes (Ciepły and Oracka, 1996) showed that efficient genotypes are characterized by: high dry matter, high nutrients content and utilization efficiency in each vegetation period and high grain yield. These genotypes had substantially longer and more active root system than the inefficient ones and their N content increased considerably after anthesis and during the milk stage. The present results demonstrate a chance for selection of efficient genotypes at earlier stages of development.

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