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Department of Agricultural and Environmental Chemistry, Agricultural University of Lublin
Akademicka 15, 20-033 Lublin, Poland

Stanisław Z. Łabuda

Balanced fertilization designed on the basis of elemental composition of crops at flowering stage

ABSTRACT. The aim of the study was to evaluate the influence of variable and decreasing levels of into-soil fertilization on the yield and element composition in cereals on the basis of a pot experiment. Six proportionally decreasing fertilizing element levels of N, P, K, Mg, S, and three cereal crops of spring wheat, spring barley and oat were experimental treatments. The composition of elements: C, N, P, K, Ca, Mg, S and Cl was determined in all above-ground parts of plants at flowering stage. Particular and mean values of intake of fertilizer components N, P, K, Mg and S for biomass production was calculated. General yield structure and harvest index was evaluated at full maturity stage. A study upon element composition in plants, yield structure, intake and utilization of fertilizer components under the influence of experimental factors point out that fertilization using low rates at constant ratios among fertilizer components can be of practical importance as a balanced fertilization.

KEY WORDS: cereals, flowering stage, element composition in plant, pot experiment.

The search for practically useful, i.e. simple for application and fertilization, recommendations versatile in every agrosystem, is a basis of conclusions made on the basis of a strict experiment. Every, even simple, fertilization way based on scientific methods, thus credible and repeatable in an experiment, must be practically simple to be commonly used. It is well known that only scientists are interested in natural conditions for fertilizing; farmers – only the profits. Although agricultural producers are interested in scientific progress in agriculture,

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even very intelligent and educated farmers are reluctant to be engaged in complicated affairs.

Among many fertilization concepts, an attempt at practical fertilization recommendations in an agrosystem was proposed. Balanced fertilization, i.e. estimation of the fertilizer component rates on the basis of ratios between elements in crops at flowering stage and on nutrient occurring in a soil at minimum level, was proposed as into-soil fertilization method. On the other hand, as a foliage nutrition, balanced fertilization would stand for the estimation of the proper element ratios in foliage fertilizers on the basis of element ratios in plants at flowering stage [Labuda 1996].

Numerous authors studied or described theoretical and practical issues of plant nutrition and fertilization [Homes 1955a, 1955b; Broeshart, Van Schouweburg 1961; Cunningham 1964a, 1964b, 1964c; Voisin 1964; Schuffelen et al. 1965; Selles 1992; Marschner 1998; Mengel et al. 2001], which are associated with usage of plant analysis before fertilization [Amberger 1980; Munson, Nelson 1990; Sanchez de la Puente, Belda 1994], as well as with fertilization recommendations [Baufils 1973; Bergmann, Neubert 1976; Archer 1988; Cerling 1990; Westfall et al. 1990; Jones et al. 1991; Isherwood 1998; Vagstad, Eggestad 1998] and utilization of variable fertilization and plant yield for estimating the fertilization recommendations [Vakhmistrov 1982].

The aim of the present study was to evaluate the influence of variable and decreasing levels of into-soil fertilization on the yielding and element composition in cereals on the basis of a pot experiment.

METHODS

The soil used in a pot experiment was sandy loam at clay content of 5%. It contained 0.69% of organic carbon, 0.08% of total nitrogen and was characterized with pH 4.6 in H_2O. Thus, it was acidic soil with a low content of available nutrients: available phosphorus – 5.2 mg P/kg, exchangeable potassium – 45.6 mg K/kg, exchangeable magnesium – 15.7 mg Mg/kg and sulfate sulfur – 0.6 mg S/kg. Each pot contained 5 kg of soil recalculated into dry matter. Soil fertilization was applied before sowing at the following rates: 0.1423 g N/kg as NH_4NO_3, 0.0253 g P/kg as $Ca(H_2PO_4)_2$ H_2O, 0.1740 g of K as KCl and K_2SO_4, 0.0072 g of Mg as $MgSO_4$ $7H_2O$ and 0.0175 g of S as K_2SO_4 and $MgSO_4$ $7H_2O$ (Tab. 1). Variable fertilization levels were the experimental factor: I – full fertilization, II – 3/4 of full fertilization, III – 1/2 of full fertilization, IV – 1/4 of full fertilization, V – 1/8 of full fertilization, VI – without fertilization (Tab. 2), as well as 3 cereal species: spring wheat, spring barley and oat.

Table 1. Elements rate and element ratios of fertilization in pot experiment

Element	Rate g/kg of soil	Fertilization element ratio		
		Element ratio	Molar ratio	Mass ratio
N	0.1423			
P	0.0253	N/P	12.4	5.6
K	0.1740	N/K	2.2	0.8
Mg	0.0072	N/Mg	33.8	19.5
S	0.0175	N/S	18.6	8.1

Table 2. Fertilizing elements applied in accordance with fertilization treatments

Element	Fertilization					
	I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0
	g/5 kg of soil					
N	0.711	0.533	0.355	0.177	0.088	0
P	0.126	0.095	0.063	0.031	0.015	0
K	0.870	0.652	0.435	0.217	0.108	0
Mg	0.036	0.027	0.018	0.009	0.004	0
S	0.087	0.065	0.043	0.021	0.010	0

Table 3. Fertilizer compounds applied according to fertilization treatments

Compound	Fertilization					
	I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0
	g/5 kg of soil					
NH_4NO_3	2.033	1.524	1.016	0.808	0.254	0
$Ca(H_2PO_4)_2$	0.515	0.386	0.257	0.128	0.064	0
KCl	1.476	1.107	0.738	0.369	0.184	0
K_2SO_4	0.213	0.160	0.106	0.053	0.026	0
$MgSO_4$ $7H_2O$	0.369	0.277	0.184	0.092	0.046	0

Table 4. Fertilizer elements according to fertilizer compound application

Element	Fertilization					
	I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0
	g/5 kg of soil					
N	0.711	0.533	0.355	0.177	0.088	0
P	0.126	0.095	0.063	0.031	0.015	0
K	0.870	0.625	0.435	0.217	0.108	0
Ca	0.062	0.061	0.041	0.020	0.010	0
Mg	0.036	0.027	0.018	0.009	0.004	0
S	0.087	0.065	0.04	0.021	0.010	0
Cl	0.702	0.526	0.351	0.175	0.087	0

Table 5. Nutrient components according to fertilizer elements application

Ion	Fertilization					
	I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0
	g/5 kg of soil					
NH_4^+	0.458	0.343	0.229	0.114	0.057	0
NO_3^-	1.574	1.181	0.787	0.393	0.196	0
$H_2PO_4^-$	0.396	0.297	0.198	0.099	0.049	0
K^+	0.870	0.652	0.435	0.217	0.108	0
Ca^{2+}	0.082	0.061	0.041	0.020	0.010	0
Mg^{2+}	0.036	0.027	0.018	0.009	0.004	0
SO_4^{2-}	0.621	0.196	0.130	0.065	0.032	0
Cl^-	0.702	0.526	0.351	0.175	0.087	0

In the experiment it was accepted that nitrogen was the component that occurred at minimum level in soil; therefore, the rates were established in accordance with molar ratios between fertilization elements. Rates of 5 fertilizer components and their ratios (Tab. 1) were differentiated with their number at 6 decreasing fertilization rates (Tab. 2) and that was the basis for the quantity of 5 fertilizer compounds applied (Tab. 3). Those compounds increased the fertilizer elements up to 7 (Tab. 4), although proper influence of fertilization on the soil and plants is expressed with the 8 nutrients applied (Tab. 5).

The experimental scheme included 3 cereal species, 6 fertilization levels in 4 replications and 3 repetitions in the years of 1992–1994. Ten cereal plants grew in each pot. Soil humidity during vegetation period was maintained at 30–50 kPa. The following items were studied: mass of the above ground parts of plants at flowering stage expressed in Feekes scale from 10.51 to 10.54 [Large 1954], as well as contents of C, N, P, K, Ca, Mg, S and Cl at flowering stage. Dry matter was determined at 105°C; carbon – using CHNS/O analyzer of series II model 2400 (Perkin-Elmer); total nitrogen – Kjeldahl's method after sample digestion in concentrated sulfuric acid with 30% H_2O_2 addition at the end of digestion; phosphorus – vanadium-molybdenum method; potassium, calcium and magnesium – AAS technique using Hitachi Z-8200 apparatus with Zeeman's polarization; chlorine – using silver nitrate applying nefelometric method with photocolorimeter Cecil 2011. Chemical analyses were carried out in two replications in every year of experiment. At full maturity, the yield structure at 85% of dry matter content in grains was estimated. The experimental data on the yield and element contents in plants were statistically worked out by means of variance analysis with cross-classification and T-Tukey's significance test.

RESULTS

The manner in which the rates of fertilization components were set results from the idea presented by the author in which five components N, P, K, Mg and S, should be taken into account at soil fertilization basing on their ratios in whole above ground parts of plants during flowering stage. The element in relation to which the ratios are calculated is that which exists at minimum level in soil [Labuda 1991].

Rates of fertilization components applied in a pot experiment (Tab. 1) were established on the basis of mean element contents in winter wheat, spring barley and oat, as well as their ratios at flowering stage [Labuda 1996]. The basis for element ratio evaluation was element composition of many plant species at flowering stage in various agrosystems, i.e. cultivation fields. The possibility to calculate the crop nutrient requirements on the basis of element contents in whole above-ground parts of plants at flowering stage using the example of faba bean [Labuda 2000] was also presented in the paper.

The content of elements in a soil is associated with the content and ratios of elements in plants, which was the objective of the study using faba bean. However, in faba bean fertilization, N/Ca, P/Ca and K/Ca ratios may play an important role, because faba bean, as leguminous plant, has high nutritional requirements for calcium [Labuda 2001].

Above-ground mass of plants at flowering stage and plant's yield expressed as the yield structure in pot experiments are presented in Table 6. The highest mass of above-ground parts of plants was found at full fertilization and it decreased along with the decreasing fertilization rates in relation to that with no fertilization: I – 5.7, II – 5.1, III – 4.1, IV – 2.9, V – 2.0. Ten numbers stand for how many times the plant's mass was greater at a given fertilization level than that with no fertilization. Decreasing of fertilization at level IV (1/4 of full fertilization rate) significantly decreased the mean mass of plants. Fertilization at levels II and III had an insignificant influence on the plant's biomass decrease at flowering stage. The yield structure, which describes the yield as a product of spike number per 10 plants, number of grains in spike and mean mass of a kernel, varied significantly. Along with the decrease of fertilization levels, the number of kernels in a spike decreased to a greatest extent. The calculated harvest index being a ratio of grain dry matter and total above-ground dry biomass of plants [Donald 1962] points out that its value did not significantly vary due to fertilization (Tab. 6).

The content of determined elements in the studied cereals are presented in Table 7. Study results are given to the nearest 0.0001 mol. Chemical elements are a specific form of matter and expressing the element content in a unit of amount of substance is the most proper way to describe their occurrence in general. Statistical analysis of the data referring to element content in plants on the basis of the amount of substance unit gave the opportunity to present the results of element composition in plants with any comparisons among all determined elements due to experimental factors applied. Furthermore, it is easy to find out, with no special calculations, differences of element content. The mean sequence of element content expressed in the amount of substance unit for spring wheat

Table 6. Yielding of crops as affected by experimental treatment

Crop	Fertilization						Mean
	I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0	
Tops at the flowering stage in g/10 plants [Chwil S. 1998. Zesz. Probl. Post. Nauk Rol. 456, 655-661]							
S. wheat	33.9	27.3	21.7	17.4	10.8	5.7	19.4
S. barley	36.1	34.1	25.5	16.5	11.5	5.2	21.5
Oat	44.2	40.9	34.2	24.8	18.6	8.9	28.6
Mean	38.1	34.1	27.1	19.5	13.6	6.6	-
LSD p = 0.01 between crops 3.0, between fertilization 11.4							
Number of ears/10 plants							
S. wheat	15.6	13.4	11.3	8.6	8.6	8.2	11.0
S. barley	27.6	25.4	19.7	12.5	10.1	10.0	17.5
Oat	14.8	13.3	10.8	9.8	9.8	10.0	11.4
Mean	19.4	17.4	14.0	10.3	9.5	9.4	-
LSD p = 0.01 between crops 0.7, between fertilizations 1.2							
Number of kernels/ear							
S. wheat	38.5	41.2	38.6	30.6	22.6	14.1	30.9
S. Barley	21.5	22.1	21.1	20.7	18.7	11.5	19.3
Oat	67.2	68.2	66.2	49.3	36.6	18.9	51.1
Mean	42.4	43.8	41.9	33.5	26.0	14.8	-
LSD p = 0.01 between crops 1.4, between fertilization 2.4							
Mean grain mass in mg/kernel							
S. wheat	32.6	31.9	33.7	31.5	34.5	30.4	32.4
S. barley	38.7	39.0	37.0	38.6	39.3	33.9	37.3
Oat	32.6	31.1	30.5	29.6	28.7	28.2	30.1
Mean	34.6	34.0	33.8	33.2	34.1	30.8	-
LSD p = 0.01 between crops 1.1, between fertilization 2.0							
Harvest index							
S. wheat	0.366	0.359	0.386	0.377	0.392	0.406	0.381
S. barley	0.473	0.487	0.458	0.488	0.482	0.498	0.481
Oat	0.500	0.495	0.484	0.476	0.476	0.483	0.485
Mean	0.446	0.447	0.442	0.447	0.450	0.462	

Table 7. Elements content in crops at the flowering stage as affected by experimental treatment

Crop	Element	Fertilization						Mean	Mean
		I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0		
		mol/kg of dry matter							
Spring wheat	C	38.4681	38.3734	38.3865	38.3768	38.2184	37.7207	38.2573	
	N	1.2757	1.1932	1.0365	0.8350	0.8496	0.8771	1.0112	5.0032
	P	0.0509	0.0492	0.0434	0.0386	0.0473	0.0629	0.0488	
	K	0.4436	0.4354	0.3990	0.3377	0.3418	0.3799	0.3896	
	Ca	0.0483	0.0494	0.0442	0.0313	0.0296	0.0427	0.0410	
	Mg	0.0271	0.0302	0.0337	0.0259	0.0395	0.0375	0.0307	
	S	0.0450	0.0484	0.0409	0.0357	0.0470	0.0713	0.0481	
	Cl	0.2500	0.2323	0.2257	0.1867	0.1831	0.1166	0.1991	
	Mean	5.0761	5.0515	5.0263	4.9835	4.9683	4.9136	-	
Spring barley	C	38.1888	38.1326	37.7136	37.9477	37.4609	37.2080	37.7753	
	N	1.2160	1.0326	0.9424	0.8143	0.7484	0.8702	0.9374	4.9371
	P	0.0435	0.0382	0.0369	0.0332	0.0392	0.0477	0.0398	
	K	0.4393	0.3876	0.3798	0.3665	0.3654	0.4117	0.3918	
	Ca	0.0780	0.0767	0.0716	0.0655	0.0604	0.0536	0.0677	
	Mg	0.0387	0.0370	0.0381	0.0400	0.0433	0.0499	0.0412	
	S	0.0467	0.0530	0.0486	0.0511	0.0612	0.1018	0.0610	
	Cl	0.2119	0.2089	0.2264	0.1891	0.1662	0.0943	0.1828	
	Mean	5.0329	4.9959	4.9322	4.9385	4.8682	4.8551	-	
Oat	C	38.8037	38.6278	38.5778	38.6767	38.9078	39.0922	38.7810	
	N	1.0734	0.9506	0.8211	0.6518	0.06331	0.6660	0.7994	5.0325
	P	0.0365	0.0336	0.0300	0.0283	0.0309	0.0430	0.0338	
	K	0.4063	0.3918	0.3791	0.3465	0.3339	0.3549	0.3688	
	Ca	0.0653	0.0616	0.0502	0.0422	0.0375	0.0555	0.0521	
	Mg	0.0443	0.0456	0.0436	0.0397	0.0363	0.0599	0.0450	
	S	0.0382	0.0357	0.0355	0.0292	0.0292	0.0438	0.0353	
	Cl	0.2197	0.2014	0.1592	0.1282	0.1062	0.0527	0.1446	
	Mean	5.0860	5.0436	5.0121	4.9929	5.0144	5.0460	-	
Mean		5.0650	5.0303	4.9902	4.9716	4.9503	4.9382	-	4.9909
Elements mean: C 38.2712, N 0.9160, P 0.0408, K 0.3834, Ca 0.0536, Mg 0.389, S 0.0481, Cl 0.1755									

LSD p = 0.01	between elements	0.1499
LSD p = 0.01	between crops	0.0708
LSD p = 0.05	between fertilizations	0.1219
LSD p = 0.01	elements *x* crops	0.3031
LSD p = 0.05	elements *x* fertilization	ns
LSD p = 0.05	plants *x* fertilization	ns

was as follows: C > N > K > Cl > P > S > Ca > Mg, for spring barley: C > N > K > Cl > Ca > S > Mg > P and for oat: C > N > K > Cl > Ca > Mg > S > P (Tab. 7). The presented sequences of element content precisely point out to deficient ones and confirm the reaction of the studied plant species according to commonly known soil requirements of these cereals. It can be checked that element content sequences – if expressed with mass unit – would line up in quite a different way: spring wheat and spring barley, too – C > K > N > Cl > Ca > S > P > Mg, and oat – C > K > N > Cl > Ca > S > Mg > P. The analysis of elemental composition of plants is made for various scientific and practical purposes. It was accepted that the flowering stage is the most interesting developmental stage, because elements taken by a plant are accumulated in their green vegetative parts. If it is assumed that all elements in ratios necessary to yield formation are included at flowering stage, an additional advantage arises: it is a comparable developmental stage for all crop species [Labuda 1997, 1998].

Table 8. Fertilizing elements used in the formation of top plants at the flowering stage as affected by experimental treatment

Crop	Element	Fertilization					
		I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0
		g/g of dry matter					
Spring wheat	N	0.020948	0.019500	0.016395	0.010223	0.008210	0
	P	0.003731	0.003473	0.002920	0.001821	0.001462	0
	K	0.025623	0.023852	0.020054	0.012505	0.010042	0
	Mg	0.001073	0.000998	0.000839	0.000523	0.000420	0
	S	0.002574	0.002396	0.002014	0.001256	0.001009	0
Spring barley	N	0.019672	0.015619	0.013951	0.010759	0.007719	0
	P	0.003504	0.002782	0.002485	0.001916	0.001373	0
	K	0.024064	0.019105	0.017065	0.013160	0.009433	0
	Mg	0.001007	0.000800	0.000714	0.000551	0.000395	0
	S	0.002417	0.001919	0.001714	0.001322	0.000947	0
Oat	N	0.016074	0.013037	0.010392	0.007163	0.004781	0
	P	0.002863	0.002322	0.001851	0.001276	0.000851	0
	K	0.019661	0.015946	0.012712	0.008761	0.005849	0
	Mg	0.000823	0.000667	0.000532	0.000366	0.000245	0
	S	0.001975	0.001602	0.001277	0.000880	0.000587	0

Utilization of fertilization components to produce plant biomass was calculated as a ratio of element accumulation to dry matter content per 10 plants (Tab. 8). Numerical data of element utilization are presented to the approximation 0.000001 g/g. Such approximation of calculated ratios gives an opportunity for an easy result reading depending on which numerical data are necessary for result interpretation.

Table 9. Mean fertilizing elements utilization in the pot experiment condition

Element	Fertilization					
	I – 1	II – ¾	III – ½	IV – ¼	V – 1/8	VI – 0
	g/g of elements applied					
N	0.782	0.698	0.775	0.752	0.739	0
P	0.320	0.329	0.312	0.304	0.326	0
K	0.620	0.672	0.713	0.780	0.793	0
Mg	0.726	0.872	0.970	0.965	0.857	0
S	0.435	0.531	0.487	0.407	0.402	0

Mean fertilizing elements utilization to produce plant biomass is presented in Table 9. The utilization was calculated according to formula: $A_f – A_0 / D$, where A_f – element accumulation in fertilized treatment, A_0 – element accumulation in treatment of no fertilization, D – applied fertilizer component in g/5 kg of soil. Numerical values of utilization are given as ratios to the approximation 0.001 g/g. Mean utilization of fertilizer components in a pot experiment was not significantly differentiated between fertilization levels, but the sequence of utilization between fertilizer components was as follows: Mg 87.8% > N 74.9% > K 71.5% > S 45.2% > P 31.2%. The highest utilization for magnesium resulted from the form of easily soluble fertilizer applied, and medium utilization of nitrogen, potassium, sulfur as well as phosphorus was symptomatic for the experiment performed.

CONCLUSIONS

1. Studies on element composition in plants, yield structure and utilization fertilization components due to experimental factors point out that fertilization using low rates at constant ratios between fertilizer components may be of practical importance as balanced fertilization.

2. Plant element composition calculated on the basis of the amount of substance unit would be a good way to evaluate the element dependencies and interaction between elements and characteristics of yield quality or environmental hazards.

3. Fertilization with five fertilizer components: nitrogen, phosphorus, potassium, magnesium and sulfur at specific ratios between fertilizer components may stabilize the natural balance of elements in an agrosystem.

4. Balanced fertilization, due to the application of low fertilizer component rates, protects from reducing effects of the lack of important nutrients for plants. Moreover, it may favor good utilization of all components applied, which was associated with reduction of losses of components used in agrosystem.

5. Further research upon balanced fertilization should focus on the hypothesis that application of low rates of five fertilizer components at proper ratios would have a much better effect than usage of one, two and even three components at higher doses, but with improper ratios between them.

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