Influence of fertilization on winter wheat in crop rotations and in long-term monoculture

M. Babulicová

Slovak Agricultural Research Centre – Research Institute of Plant Production, Piešťany, Slovak Republic

ABSTRACT

The effect of mineral and organic fertilization on grain yield and quality of winter wheat in crop rotations and in continuous cropping was investigated. The study was conducted in Borovce (near Piešťany) on Luvi-Haplic Chernozem in the years 2002–2004. Mineral and organic fertilization of winter wheat growing in monoculture was more effective than mineral fertilization in crop rotations. In the case of winter wheat growing in monoculture, statistically higher grain yield (5.10 t/ha) was obtained in the variant with straw and green manure incorporation compared to the control variant (4.73 t/ha) and the variant with straw incorporation (4.75 t/ha). In the Solara variety, statistically higher number of plants before harvest was recorded in the variant with straw and green manure incorporation (194 plants per 1 m^2) than in the variant with straw incorporation only (149 plants per 1 m^2). As for the winter wheat grain in the sequence 2, based on the wet gluten content (30.3%) the Solara variety was classified in the elite class E in the variant with straw and green manure incorporation, and in the improving class A in the control variant.

Keywords: winter wheat; crop rotation; long-term monoculture; fertilization; straw incorporation; green manuring

Winter cereals are very important in the capacity of plant production and revenue. To achieve stable grain yields it is necessary to use an exact agricultural technology, which comprises a sequel of growing measurements including precise fertilization. Requirements of plants for nutrients are fulfilled with fertilization, while respecting growing profitability, productive potential of specific stand and environmental limits. The success of winter wheat growing largely depends on harmonization of nutrient disposals from soil supplies and the crops requirements in the process of yield production. The medium, adequate or good content of accessible nutrients in soil should be considered. In the last decade the content of available nutrients in soil in Slovakia was reduced; this was proved by the results of agrochemical soil testing carried out by the Central Inspection and Experimental Institute for Agriculture in Bratislava. The consumption of nutrients from soil by main and additional product is higher than the input of nutrients into soil by mineral and organic fertilizers. The use of cereals in crop rotations was increasing especially in fertile areas of maize and sugar beet production; in some cases it led to monoculture growing. As the results obtained in a number of experiments suggest, repeated cereal growing, especially if it is long-term, may bring some problems. It mostly causes a yield stability decrease (Arshad et al. 2002, Elen 2002, and others). Moreover, as the number of farm animals considerably lowers, the organic fertilizers production decreases. The straw of cereals remaining in the fields is the main source of basic organic matter supplied to the soil. The high concentration of cereals brings about negative effects that can be compensated by the precise volume of organic matter. In order to approach fertilization level of Western European countries we must reassess the present fertilization system and put into practice at least the replacement fertiliza-

Supported by the Slovak Research and Development Agency (APVV), Project No. APVV-0645-06.

This article was presented at the conference "Practical Solutions for Managing Optimum C and N Content in Agricultural Soils IV", 19–23 June 2007, Prague, Czech Republic.

tion system. Determination of complex amounts of nitrogen, phosphorus and potassium is considered as a balance methodology; it determines the amounts of nutrients according to supposed yields, content of nutrients in the soil and with respect to the utility of fertilizer nutrients. Many national and foreign authors confirm that a right supply of nutrients in the soil eliminates, in a respectable measure, the variations of grain yield induced by the deficit of rainfall and abnormal temperatures (Vaněk et al. 1999, Jamriška et al. 2004).

The forecast of global increase of temperatures will be important for adequate nutrition and fertilization of plants resulting in stabilization of agricultural crops yields (Ložek and Soychaj-Fabisiak 2005).

The aim of this paper was to determine the effects of winter wheat fertilization on the grain yield, yield formation attributes and the grain quality in the long-term monoculture and in the crop rotations with 40, 60 and 80% share of cereals.

MATERIAL AND METHODS

Stationary trial was established in 1974 in the experimental station Borovce of the Research Institute of Plant Production in Piešťany. The field experiment was located on Luvi-Haplic Chernozem on loess. The depth of plow-layer was 0.24–0.28 m. The depth of molic horizon was 0.40–0.55 m; it was differentiated in the upper (eluvial) and under (illuvial) layer. In the depth of 0.50–0.85 m molic horizon proceeded into calciferous loess. The content of humus was medium (1.8–2.0%), in the plowpan it was low. The soil was characterized by mean to good content of phosphorus, good to high content of potassium, high content of magnesium (the analysis according to Mehlich II). The climate in the trial area was characterized as continental; the average annual temperature was 9.2°C, the average temperature of vegetation period was 15.5°C, the sum of the annual precipitation was 593 mm (30-year average), the sum of vegetation period precipitation was 358 mm. The trial consisted of two parts. In the first part, crop rotations were used with 40, 60 and 80% share of cereals. In the crop rotation with 40% cereal share, following crops were used: pea, winter wheat, silage maize, spring barley and grain maize. In the crop rotation with 60% cereals, it was pea, winter wheat, winter barley, silage maize and spring barley. In the case of 80% of cereals, winter wheat, spring barley, pea, winter wheat and winter barley were grown. Two levels of fertilization were applied: H_1 level consisted in nitrogen in the total dosage of 90 kg/ha, phosphorus in the dosage of 35 kg/ha and potassium in the dosage of 80 kg/ha (Table 1); H_2 included nitrogen in the total dosage of 120 kg/ha, phosphorus – 10 kg/ha, and potassium – 25 kg/ha (the dosages of P and K were calculated according to the balance methodology (Bizík et al. 1998) (Table 2). In the first part of the trial, winter wheat cultivar Solara was grown. In the second part of the trial, winter wheat (cvs. Solara and Zerda) and spring barley were grown in monoculture. In the first sequence winter wheat was grown in "net" monoculture. Three variants of fertilization were used. In the control variant only fertilizers were used. In the second variant incorporation of straw of the cereals was used. In the third variant straw and green manure were applied. In the

Table 1. The dosage of N, P, K nutrients at the level of fertilization H_1

Forecrop	Crop	N	P	K
		(kg/ha)		
Peas	winter wheat	90	35	80
Maize on silage	spring barley	30	35	80
Winter wheat		50		
Winter wheat	winter barley	90	35	80
Winter wheat	maize on silage	100	35	80
Winter barley		110		
Spring barley	grain maize	110	35	80
Grain maize	peas		35	80
Spring barley				

Table 2. The dosage of N, P, K nutrients at the level of fertilization H_2 (according to the balance methodology): years 2001/2002 to 2003/2004

SC[1] (%)	Forecrop	2001/2002					2002/2003					2003/2004				
		autumn – before sowing			spring – growth stage		autumn – before sowing			spring – growth stage		autumn – before sowing			spring – growth stage	
					BBCH[2] 21–25	BBCH[3] 30				BBCH[2] 21–25	BBCH[3] 30				BBCH[2] 21–25	BBCH[3] 30
		N	P	K	N	N	N	P	K	N	N	N	P	K	N	N
		(kg/ha)					(kg/ha)					(kg/ha)				
40	peas	30	0	0	45	45	30	0	0	45	45	45	10	25	30	30
60	peas	30	0	0	45	45	30	10	25	45	45	30	10	25	45	45
80	peas	30	10	25	45	45	30	10	25	45	45	45	10	25	45	45
80	winter barley	15	0	0	30	30	15	10	25	30	30	60	10	25	30	30

[1]SC – share of cereals in crop rotations; [2]BBCH 21–25 – growth stage: beginning of stooling – stooling peak; [3]BBCH 30 – growth stage: culm

second sequence winter wheat and spring barley rotated and two variants of fertilization were used. In the control variant only fertilizers were used. In the other variant within the second sequence, straw of cereals and green manure were applied. The third sequence consisted of maize for silage incorporated in every other year in growing winter wheat in monoculture. In the fourth sequence oat was sown every other year in monoculture of winter wheat and spring barley. To decrease the negative impacts of monoculture growing, various measures were taken, e.g. incorporation of organic matter into soil (cereal straw and/or cereal straw and green manure) and the introduction of compensating crops (silage maize, grain maize, oat). In the years 2002–2004 we evaluated the number of overwintered plants, the number of plants before harvest, the number of ears per 1 m^2, grain yield and qualitative parameters of winter wheat grain. Grain yield, yield formation attributes and winter wheat grain quality were evaluated using the analysis of variance.

RESULTS AND DISCUSSION

In crop rotations, the number of overwintered plants was statistically influenced by fertilization, by climatic conditions in particular years, by the interaction between fertilization and particular years and by the interaction between the share of cereals and particular years (Table 4). Statistically higher number of overwintered plants was found at the fertilization level H_2 (the fertilization according to the balance methodology) than at the level H_1 (Table 3). On the other hand, in the case of winter wheat grown in monoculture, the number of overwintered plants was influenced by climatic conditions of particular years only (Table 6). The number of plants before harvest in crop rotations was statistically influenced by climatic conditions of particular years. In the case of winter wheat grown in monoculture the number of plants before harvest in the sequence 1 was affected by climatic conditions of particular years, by the interaction between the fertilization and variety and the interaction between variety and the particular year. In the Solara variety, statistically higher number of plants before harvest was found in the variant with straw and green manure incorporation (194 pieces/m^2) than in the variant with straw incorporation only (149 pieces/m^2) in the sequence 1 (Table 5). As for the number of ears in crop rotations, it was influenced in a statistically

Table 3. Grain yield (t/ha), yield-supporting elements and the qualitative parameters of winter wheat in crop rotations with 40, 60 and 80% share of cereals

SC (%)	PC	F	NOP	NPBH	NE (ears per 1 m²)	GY (t/ha)	WGC (%)	SI (ml)	FN (s)
			(plants per 1 m²)						
40	peas	H_1	365	188	574	6.24	31.0	73.4	333
		H_2	390	179	587	6.14	32.4	76.6	341
		average	377	184	581	6.20	31.7	75.0	337
60	peas	H_1	351	178	545	5.85	32.3	74.1	344
		H_2	388	177	531	6.05	31.4	74.5	340
		average	369	177	538	5.95	31.9	74.3	342
80	peas	H_1	331	174	519	5.39	29.3	71.3	334
		H_2	395	165	507	5.52	31.8	75.5	324
		average	363	170	513	5.45	30.5	73.4	329
80	winter barley	H_1	325	182	521	5.17	28.4	71.8	329
		H_2	394	175	516	4.90	28.7	71.9	323
		average	359	179	518	5.03	28.5	71.8	326
Average			367	177	548	5.66	30.7	73.6	333

NOP – number of overwintered plants; NPBH – number of plants before harvest; NE – number of ears per square meter; GY – grain yield; WGC – wet gluten content; SI –sedimentation test; FN – falling number; SC – share of cereals in crop rotations; PC – preceding crop; F – fertilization

Table 4. Multifactorial analysis of variance (winter wheat in crop rotations)

Source of variability		NOP	NPBH	NE (ears per 1 m²)	GY (t/ha)	WGC (%)	SI (ml)	FN (s)
		(plants per 1 m²)						
Fertilization (A)	$LSD_{0.05}$	14.42	15.31	30.31	0.16	2.40	2.08	11.01
	P^{10}	++	–	–	–	–	+	–
SC (B)	$LSD_{0.05}$	21.24	22.56	44.66	0,24	3.54	3.07	16.21
	P^{10}	–	–	+	++	–	–	–
Years (C)	$LSD_{0.05}$	21.24	22.56	44.66	0.24	3.54	3.07	16.21
	P	++	++	++	++	++	++	++
A × B	$LSD_{0.05}$	36.86	39.14	77.48	0.42	6.14	5.32	28.13
	P	–	–	–	–	–	–	–
A × C	$LSD_{0.05}$	36.86	39.14	77.48	0.42	6.14	5.32	28.13
	P	++	–	–	–	–	–	–
B × C	$LSD_{0.05}$	49.39	52.44	103.82	0.56	8.23	7.13	37.69
	P	++	–	++	++	–	–	–

NOP – number of overwintered plants; NPBH – number of plants before harvest; NE – number of ears per square meter; GY – grain yield; WGC – wet gluten content; SI –sedimentation test; FN – falling number; SC – share of cereals in crop rotations; $LSD_{0.05}$ – least significant α = 0.05; P – effect of factor significant at the level α = 0.05 or α = 0.01

significant degree by particular year and by the share of cereals; in monoculture in sequence 2, statistically significant differences were found in dependence on climatic conditions in particular years, variety and the interaction between fertilization and variety. The number of ears was statistically higher (559 pieces/m^2) in the Solara variety than the Zerda variety (426 pieces/m^2) in the variant with straw and green manure incorporation. The grain yield in crop rotations was statistically significantly influenced by the share of cereals, by the particular year and by the interaction between the share of cereals and the particular year. There were no significant differences in the winter wheat grain yield caused by different fertilization in crop rotations with 40, 60 and 80% share of cereals. However, in the case of winter wheat growing in the monoculture in the sequence 1, the grain yield was influenced by fertilization, variety and climatic conditions in particular years. Statistically higher grain yield (5.10 t/ha) was recorded in the variant with straw and green manure incorporation than in the variant with straw incorporation only (4.70 t/ha). In winter wheat growing in monoculture in the sequence 2 the grain yield was influenced by variety, climatic conditions in particular years and by interaction between variety and climatic conditions in particular years.

The baking attributes were determined with respect to the Slovak Technical Norm (STN 2003). The wet gluten content, sedimentation test and falling number were evaluated. The sedimentation test according to Axford was used. The results of the sedimentation test and falling number show that according to the Slovak Technical Norm (STN) the winter wheat grain was classified into the elite class E irrespective of the share of cereals in crop rotations. Based on the values of wet gluten content in this norm, the winter wheat grain was classified into the elite class E when grown in the system of 40 and 60% share of cereals; at 80% share of cereals after winter barley it was classified into the improving class A (Table 3). Zerda variety was classified into the elite class E when grown in monoculture in sequence 1 and 2, whereas Solara variety was classified in the improving class A in the sequence 1; in the sequence 2 it was classified in the improving class A in the variant with mineral fertilization (C variant) and in the elite class E in the variant with straw and green manure incorporation.

Table 5. Grain yield (t/ha), yield-supporting elements and the qualitative parameters of winter wheat in monoculture

SQ	F	Variety	NOP	NPBH	NE	GY	WGC	SI	FN
			(plants per 1 m^2)		(ears per 1 m^2)	(t/ha)	(%)	(ml)	(s)
1	C	Solara	377	158	409	5.14	26.8	69.1	313
		Zerda	385	185	483	4.44	32.3	69.3	171
	ST	Solara	367	149	488	5.02	28.3	71.1	333
		Zerda	375	166	426	4.37	33.7	72.7	174
	ST + GM	Solara	373	194	460	5.51	28,9	73.8	326
		Zerda	388	170	438	4.69	34.7	74.2	177
	average		380	171	451	4,86	30.8	71,7	249
2	C	Solara	372	178	462	5.30	28.3	73.2	327
		Zerda	391	163	488	4.81	33.4	74.1	180
	ST + GM	Solara	390	203	531	5.25	30.3	74.4	332
		Zerda	366	173	426	4.59	33.5	74.3	192
	average		377	179	477	5.00	31.4	74.0	258

NOP – number of overwintered plants; NPBH – number of plants before harvest; NE – number of ears per square meter; GY – grain yield; WGC – wet gluten content; SI – sedimentation test; FN – falling number; SQ – sequence; F – fertilization; C – control variant (mineral fertilization only); ST – mineral fertilization + incorporation of straw cereals; ST + GM – mineral fertilization + incorporation of straw cereals + incorporation of green manure (plants of mustard)

Table 6. Multifactorial analysis of variance (winter wheat in monoculture)

Source of variability		NOP (plants per 1 m²)	NPBH (plants per 1 m²)	NE (ears per 1 m²)	GY (t/ha)	WGC (%)	SI (ml)	FN (s)
Sequence 1								
Fertilization (A)	$LSD_{0.05}$	38.93	24.71	60.74	0.39	2.70	4.59	15.57
	P^9	–	–	–	+	–	–	–
Variety (B)	$LSD_{0.05}$	26.14	16.59	40.79	0.26	1.81	3.08	10.46
	P	–	–	+	++	++	–	++
Years (C)	$LSD_{0.05}$	38.93	24.71	60.74	0.39	2.70	4.59	15.58
	P	++	++	++	++	++	–	++
A × B	$LSD_{0.05}$	68.64	43.57	107.11	0.69	4.76	8.10	27.47
	P	–	+	–	–	–	–	–
A × C	$LSD_{0.05}$	92.75	58.87	144.72	0.94	6.44	10.94	37.19
	P	–	–	–	–	–	–	–
B × C	$LSD_{0.05}$	68.64	43.57	187.11	0.69	4.76	8.10	27.47
	P	–	+	–	–	–	++	++
Sequence 2								
Fertilization (A)	$LSD_{0.05}$	33.63	29.51	55.49	0.23	2.05	3.15	13.65
	P	–	–	–	–	–	–	–
Variety (B)	$LSD_{0.05}$	33.63	29.51	55.49	0.23	2.05	3.15	13.65
	P	–	–	+	++	++	–	++
Years (C)	$LSD_{0.05}$	50.55	44.35	83.40	0.34	3.08	4.73	20.51
	P	++	++	++	++	++	++	++
A × B	$LSD_{0.05}$	65.03	57.05	107.30	0.44	3.96	6.09	26.39
	P	–	–	+	–	–	–	–
A × C	$LSD_{0.05}$	90.25	79.18	148.92	0.61	5.50	8.45	36.62
	P	–	–	–	–	–	–	–
B × C	$LSD_{0.05}$	90.25	79.18	148.92	0.61	5.50	8.45	36.62
	P	–	–	–	++	–	++	–

NOP – number of overwintered plants; NPBH – number of plants before harvest; NE – number of ears per square meter; GY – grain yield; WGC – wet gluten content; SI –sedimentation test; FN – falling number; $LSD_{0.05}$ – least significant α = 0.05; *P* – effect of factor significant at the level α = 0.05 or α = 0.01

The sedimentation index was influenced by fertilization in a statistically significant degree (Table 4). At fertilization level H_2 (75.5 ml) the attributes of sedimentation index were statistically higher than at H_1 (72.9 ml). There were no significant differences in the grain yield of winter wheat at different nitrogen fertilization levels H_1 (90 kg/ha) and H_2 (120 kg/ha) in crop rotations with 40, 60 and 80% share of cereals. Horvat et al. (2006) pointed out that the fertilization with 200 kg N/ha increased grain yield significantly compared to 80 kg N/ha; they also found that wet gluten and sedimentation values were significantly ($P < 0.001$) affected by N fertilization treatments.

Many researchers evaluated the effects of straw incorporation into soil on yields of consecutive crops and changes in the soil environment (Christian and Bacon 1991, Smallfield 1992, Borresen 1999, etc.). Straw can inhibit germination, emergence and initial growth of consecutive crops. The inhibition mostly comprises physical and biochemical effects (water consumption for straw decomposition, phytotoxic substances released from straw or produced at its degradation). Such problems are more frequent under drier conditions and in growing winter cereals, since there is a short period between straw incorporation into soil and seeding. Turley et al. (2003) studied the effects of chopped wheat (*Triticum aestivum*) straw incorporation into soil by tine cultivation (non-soil inversion) or ploughing; it was compared with burning straw followed by tine cultivation at six sites in England over a period of 11 years. Three sites had clay soils and three silty clay loam soils. The yield reduction by straw incorporation into soil ranged from 5 to 8% on clay soils and from 3 to 18% on silty clay loam soils. Ploughing straw into soil had only an occasional adverse effect on the yield of following crops. Procházková et al. (2003) observed that the effect of organic amendment on winter wheat continuous cropping was statistically significant. On the average of the whole period (32 years), the highest yields were produced in variants with straw burning (var. 5) – 6.04 t/ha and with green manuring (var. 2) – 6.03 t/ha, and lower yields in variants with straw incorporation into soil (var. 3) – 5.65 t/ha, and with straw incorporation into soil + green manuring (var. 4) – 5.67 t/ha. The smallest differences between variants were found in the first decade of the experiment. Over time (in the second and third decade), the differences were more significant and positive effects of green manuring and straw burning as well as adverse effects of straw incorporation into soil increased.

REFERENCES

Arshad M.A., Soon Y.K., Azooz R.H. (2002): Modified no-till and crop sequence effect on spring wheat production in northern Alberta, Canada. Soil Till. Res., *65*: 29–36.

Bizík J., Fecenko J., Kotvas F., Ložek O. (1998): The Methodology of Plant Fertilization and Nutrition. Bratislava. (In Slovak)

Borresen T. (1999): The effect of straw management and reduced tillage on soil properties and crop yields of spring cereals on two loam soils in Norway. Soil Till. Res., *51*: 91–102.

Christian D.G., Bacon E.T.G. (1991): The effect of straw disposal and depth of cultivation on the growth, nutrient uptake and yield of winter wheat on clay and silt soil. Soil Use Manag., *7*: 217–222.

Elen O. (2002): Plant production in spring cereal production with reduced tillage. III. Cereal diseases. Crop Prot., *21*: 195–201.

Horvat D., Loncaric Z., Vukadinovic V., Drezner G., Bertic B., Dvojkovic K. (2006): The influence of mineral fertilization on winter wheat yield and quality. Cereal Res. Commun., *34*: 429–432.

Jamriška P., Hašana R., Rúckschloss Ľ. (2004): The influence of N, P, K and Mg fertilization on grain yield of winter wheat. Agrochémia, *3*: 8–11. (In Slovak)

Ložek O., Soychaj-Fabisiak E. (2005): Optimal level of nutrition and fertilization positively influences the yields of agricultural crops. Agrochémia, *45*: 16–19. (In Slovak)

Procházková B., Hrubý J., Dovrtěl J., Dostál O. (2003): Effects of different organic amendment on winter wheat yields under long-term continuous cropping. Plant Soil Environ., *49*: 433–438.

Slovak Technical Norm 46 1100-2 (2003): Food Cereals, Part 2: The Grain of Winter Wheat. (In Slovak)

Smallfield B.M. (1992): Influence of straw residues on the growth of winter wheat. Diss. Abstr. Int. B Sci. Eng., *53*: 619B.

Turley D.B., Philips M.C., Johnson P., Jones A.E., Chambers B.J. (2003): Long-term straw management effects on yields of sequential wheat (*Triticum aestivum* L.) crops in clay and silty clay loam soils in England. Soil Till. Res., *71*: 59–64.

Vaněk V., Balík J., Němeček R., Pavlíková D., Tlustoš P. (1999): The Nutrition and Fertilization of Field Crops, Fruits and Vegetables. Farmář, Prague. (In Czech)

Received on February 13, 2008

Corresponding author:

Ing. Mgr. Mária Babulicová, Ph.D., Slovenské centrum poľnohospodárskeho výskumu, Výzkumný ústav rastlinej výroby Piešťany, Bratislavská cesta 122, 921 01 Piešťany, Slovenská republika
e-mail: babulicova@vurv.sk