Effects of different organic amendment on winter wheat yields under long-term continuous cropping

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ABSTRACT

The observations were conducted on chernozem soil in a sugar-beet production region in 1971–2002. Six variants of organic amendment were examined: 1 – straw harvest, 2 – straw harvest + green manuring, 3 – straw incorporation, 4 – straw incorporation + green manuring, 5 – straw burning, 6 – straw burning till 1977 + intercrop, incorporation of farmyard manure at 10 t/ha since 1978. The effect of organic amendment on winter wheat continuous cropping was statistically significant. On 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, (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 decades), the differences increased and positive effects of green manuring and straw burning and adverse effects of straw incorporation into soil increased. The yield level of winter wheat continuous cropping was high under the given conditions. The yield for the whole period of the experiment averaged 5.85 t/ha, the yields 5.19, 6.54 and 5.76 t/ha were obtained in the first, second and third decade, respectively.

Keywords: winter wheat; long-term continuous cropping; straw management; green manuring; farmyard manuring; grain yield

The concentration of cereals in crop rotations has been increasing, particularly in the fertile areas of maize and sugar-beet production regions, and in some cases they tend up to continuous cropping. The agricultural enterprises specialized in cereal growing do not usually have livestock production or cattle breeding. Thus, cereal straw remains in the field and is a main source of essential organic matters supplied to the soil.

As the results obtained from a number of experiments suggest, repeated cereal growing (in particular for a long time) is not without problems. It mostly leads to yield and yield stability decrease (Zawislak and Sadowski 1992, Arshad et al. 2002, Elen 2002, and others). The yield level depends on the site to a considerable extent. Under some conditions, high and stable yields can be produced even at the high proportion of cereals. In relation to the crop concentration and continuous cropping, the so-called antiphytopathogenic potential of soil is discussed, which means the soil is able to destroy pathogenic soil organisms.

A great number of researchers have been engaged in the evaluation of 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, and others). Their results show that straw manuring, particularly combined with shallow soil tillage, often generates problems associated with the proper stand establishment. Furthermore, 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. Annual straw manuring at repeated cereal growing usually leads to an abundant supply of soil with organic matter. Both deficient and excessive supply of organic matter to soil can adversely affect the quality of the soil environment and grown crops.

The unfavourable effects of the higher cereal concentration can be compensated to a certain extent (Bowerman et al. 1995, Agenbag 1998, Berzsenyi et al. 1999, and others). It is recommended to take the following measures: to increase nutrient supply to soil, to grow intercrops as green manure, to support post-harvest residue and straw decomposition, to select appropriate varieties, and to apply chemical plant protection. Straw burning also has a favourable influence on yields and their stability, especially due to its phytosanitary effects. However, its application is markedly limited because of technical problems and environmental impacts.

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The aim of the present paper is to evaluate the effects of different practices of organic amendment on yields of winter wheat under long-term continuous cropping.

MATERIAL AND METHODS

The study was conducted in a stationary field experiment carried out in a sugar-beet production region in the field of the Research Institute of Crop Production Prague-Ruzyně in 1971–2002. The experiment was arranged in a split-plot design in four replications. The plot size was 20 m^2.

Characteristics of experimental site

The site is 225 m above sea level, average annual temperature 9.05°C, and average precipitation 537.3 mm (average of 1971–2002). Data on weather characteristics during the experiment are given in Table 1. Soil conditions of the experimental site: chernozem soil of medium texture originated on pleistocene loess, neutral soil reaction, content of available phosphorus and potassium is good.

Variants

1. straw harvest
2. straw harvest + green manuring (white mustard)
3. straw incorporation
4. straw incorporation + green manuring
5. straw burning
6. till 1976 – straw burning + green manuring
   since 1977 – farmyard manure at a rate of 10 t/ha

Mineral fertilization regimes: phosphorus and potassium rates till 1975 – 24 and 66 kg pure nutrients per ha, respectively, since 1976 – 40 and 100 kg pure nutrients per ha, respectively, nitrogen rate over the whole period of the experiment – 120 kg per ha.

The varieties were changed during the experiment; Soviet varieties were grown mostly in the first decade and home varieties in the second and third decades. Harmful agents were controlled uniformly in all variants of the experiment using methods of the State Phytosanitary Administration. Yield data were statistically processed by analysis of variance and least significant differences were calculated. Relative yields were used to compute yield trends in individual variants of organic amendment (basic variant – straw harvest).

RESULTS

The effect of different organic amendment on yields of winter wheat under a long-term continuous cropping system was statistically significant for both individual decades and the whole period of the experiment. The results are presented in Table 2 and Figure 1.

In the first decade (1971–1980), the differences between variants were smallest. The highest yield was obtained in the variant with straw harvest in combination with green manuring (var. 2) and in the control variant with straw harvest (var. 1).

In the second decade (1981–1990), the differences between variants were larger. The highest yields were recorded after green manuring (var. 2) and straw burning (var. 5). Yields began to decrease after straw incorporation into soil (var. 3 and 4).

In the third decade (1991–2000), the differences between variants were the largest. The highest yields were obtained after straw burning (var. 5), after green manuring (var. 2), and after farmyard manuring (var. 6). Straw incorporation into soil showed apparent negative effects. A highly significant difference was found between the

Table 1. Weather characteristics

Year	Average monthly temperatures (°C)												
	1	2	3	4	5	6	7	8	9	10	11	12	mean
1971–1980	–1.61	0.48	4.32	8.11	13.69	16.75	17.91	23.22	13.46	7.77	3.35	0.43	8.99
1981–1990	–2.64	–1.25	3.78	8.99	14.61	16.63	18.79	18.31	14.49	9.39	2.77	–0.27	8.63
1991–2000	–1.26	–0.09	3.84	9.60	14.61	17.81	19.61	19.72	14.53	9.02	3.06	–0.79	9.14
1971–2002	–0.79	–0.11	4.05	8.89	14.47	17.11	18.90	20.43	14.11	8.81	3.13	–0.44	9.05
Year	Monthly precipitation (mm)												
	1	2	3	4	5	6	7	8	9	10	11	12	sum
1971–1980	31.6	26.4	27.0	50.3	56.7	64.2	78.6	60.5	36.3	39.6	39.9	24.3	535.4
1981–1990	18.6	31.2	24.8	28.5	66.7	87.1	63.3	60.3	45.2	32.6	33.1	34.9	526.3
1991–2000	19.2	18.1	34.5	32.3	60.6	68.4	78.0	61.1	55.1	39.8	44.6	30.4	542.1
1971–2002	23.5	24.9	29.1	36.9	60.0	71.7	73.9	62.7	47.9	37.9	38.8	30.1	537.3

Table 2. Yields of winter wheat continuous cropping at different organic amendment (t/ha)

Years	Variants of organic amendment						Mean	*Dt*	
	1	2	3	4	5	6		$p = 0.05$	$p = 0.01$
1971	4.66	4.72	5.01	4.90	4.77	4.95	4.84		
1972	4.53	4.60	4.55	4.45	4.61	4.56	4.55		
1973	4.55	4.51	4.57	4.55	4.55	4.48	4.54		
1974	5.41	4.94	5.64	5.19	5.37	4.62	5.20		
1975	3.59	3.72	3.88	3.88	3.82	3.94	3.81		
1976	4.85	4.78	4.55	4.51	4.97	4.55	4.70		
1977	5.29	5.63	5.02	5.29	5.32	5.41	5.33		
1978	7.32	7.73	6.82	7.24	6.75	7.12	7.16		
1979	5.03	5.16	4.29	4.85	4.88	4.77	4.83		
1980	7.09	6.83	7.33	6.17	6.58	7.47	6.91		
Mean	5.23	5.26	5.17	5.10	5.16	5.19	5.19	0.089	0.105
1981	5.58	6.22	5.60	5.30	5.88	5.79	5.73		
1982	7.26	7.45	7.03	6.95	7.20	7.04	7.16		
1983	6.62	6.82	6.78	6.31	6.55	6.36	6.57		
1984	5.36	6.14	5.13	5.12	4.87	4.49	5.19		
1985	7.59	7.78	6.91	7.27	7.83	7.36	7.46		
1986	5.34	5.67	5.30	5.44	5.68	5.72	5.52		
1987	7.12	7.36	7.12	6.84	7.46	7.28	7.20		
1988	6.71	6.88	6.70	6.87	6.98	6.80	6.83		
1989	6.69	7.16	6.67	6.78	6.78	6.93	6.83		
1990	6.79	7.03	6.79	6.87	7.31	6.77	6.93		
Mean	6.51	6.85	6.40	6.38	6.65	6.45	6.54	0.129	0.152
1991	5.66	5.75	4.81	4.98	5.60	5.93	5.45		
1992	5.06	6.27	3.68	4.78	8.26	7.12	5.86		
1993	4.79	5.27	4.90	4.98	5.06	5.59	5.10		
1994	7.93	7.75	7.57	7.80	7.82	7.93	7.80		
1995	5.90	6.61	6.19	5.88	7.02	6.58	6.28		
1996	5.08	5.61	5.00	5.30	5.37	5.25	5.27		
1997	5.04	5.30	5.23	5.11	5.29	5.36	5.22		
1998	4.92	5.27	5.08	4.92	5.75	5.54	5.25		
1999	5.20	5.31	5.17	5.17	5.17	5.45	5.24		
2000	6.45	6.61	6.10	6.18	6.37	5.14	6.14		
Mean	5.60	5.98	5.37	5.51	6.17	5.99	5.76	0.164	0.192
2001	5.51	5.96	5.67	5.26	6.69	6.50	5.93		
2002	6.62	6.22	5.70	6.28	6.61	6.34	6.30		
Mean 1971–2002	5.80	6.03	5.65	5.67	6.04	5.91	5.85	0.074	0.087

control variant with straw harvest (var. 1) and the variant with straw incorporation into soil (var. 3).

On average of the whole period of the experiment (1971–2002), the highest yield was obtained in the variant with straw burning (var. 5) and in the variant with green manuring (var. 2); the lowest one in the variant with straw incorporation into soil (var. 3).

Relative yields were used to calculate yield trends in individual variants of organic amendment (basic variant – straw harvest). The results are given in Figure 2 and Table 3. The highest yield increase in comparison with the control variant was recorded in the variant with straw burning (var. 5), in the variant with farmyard manuring (var. 6), and with green manuring (var. 2). Over time, straw incorporation into soil (var. 3) led to yield decrease in comparison with the control variant.

Winter wheat continuous cropping produced high yields at the site on fertile chernozem soil in the sugar-beet production region. The yield for the whole period averaged 5.85 t/ha, the yields 5.19, 6.54 and 5.76 t/ha were obtained in the first, second and third decade, respectively.

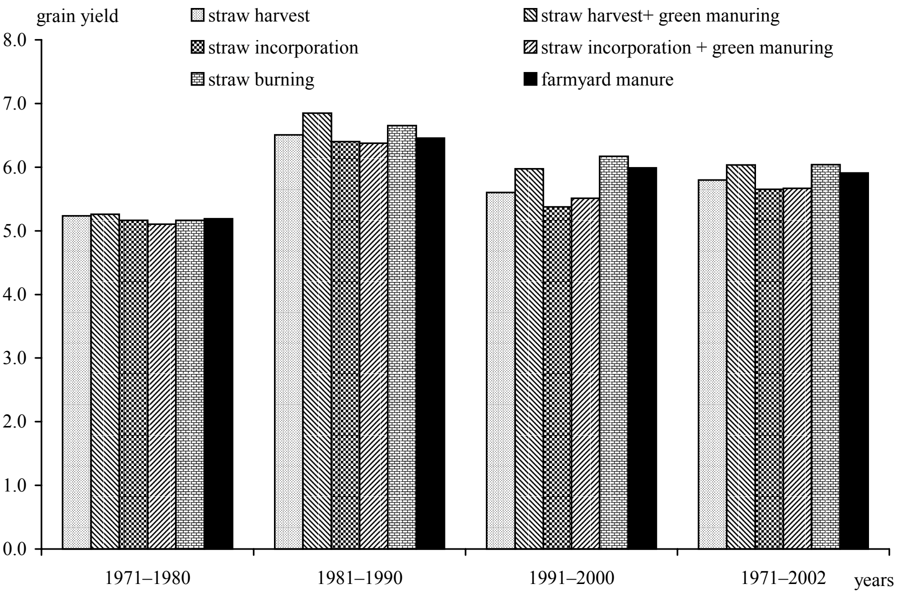

Figure 1. Effect of different organic amendment on yields of winter wheat continuous cropping (t/ha)

DISCUSSION

Topical questions of current agricultural practice are if a higher concentration of cereals in crop rotations is possible and if they can be grown repeatedly. The research on the higher cereal concentration and associated problems shows that agroecological conditions play a critical role. Based on long-term investigations, Kos (1982) stated that the most favourable conditions for the high cereal concentration in crop rotations were in the sugar-beet chernozem production region. The high cereal concentration in less favourable areas is mostly accompanied by a larger decrease in grain yields. The importance of soil suppressivity for higher cereal concentrations was reported by Smiley (1979).

In our experiments, the yields of winter wheat continuous cropping were high. The yield reduction vs. wheat in the crop rotation did not exceed 10%. This high production ability of long-term winter wheat continuous cropping evinces a high antiphytopathogenic potential of the soil concerned. The results are quite good and confirm that chernozem soils in the sugar-beet produc-

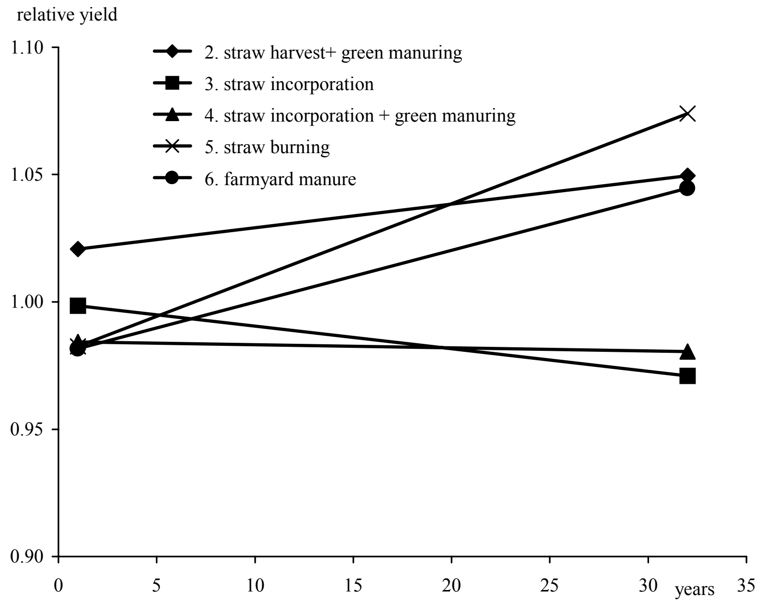

Figure 2. Yield trends in winter wheat continuous cropping at different organic amendment in 1971–2002 (relative yields, basic variant – straw harvest)

Table 3. Statistical assessment of yield trend parameters

Variant	Parameters of line $y = a + bx$		Limits of parameter b (p = 0.05)		p-significance of parameter b
	a	b	lower	upper	
2. straw harvest + green manuring	1.01985	0.00093	–0.0010	0.0028	0.332
3. straw incorporation	0.99938	–0.00089	–0.0032	0.0015	0.444
4. straw incorporation + green manuring	0.98443	–0.00012	–0.0019	0.0017	0.891
5. straw burning	0.97958	0.00295	0.0004	0.0054	0.022
6. farmyard manure	0.97962	0.00203	–0.0013	0.0054	0.225

tion region are favourable for higher cereal concentration.

The higher concentration of cereals necessitates paying attention to a complex of measures in order to eliminate adverse implications of their repeated growing.

Infection of cereals by stem-base diseases is one of the important factors that limit the higher cereal concentration in crop rotations. Comprehensive and long-term investigations into the effect of higher cereal concentration in the crop rotation on the development of stem-base diseases were conducted by Kos (1982). The results confirmed considerable importance of ecological conditions in relation to disease severity. He accounted the sugar-beet chernozem production region medium endangered and did not consider the infection by stem-base diseases as the only cause of yield reduction in cereals at their higher concentration in the crop rotation. He reported a slight decrease in disease severity in winter wheat continuous cropping after green manuring, straw incorporation, and application of farmyard manure. The infection was more suppressed after straw burning.

A problem of the higher cereal concentration can be repeated straw incorporation into soil. If straw is decomposed slowly, particularly under drier conditions, a larger amount of undecomposed organic matters can induce the inhibition of germination and initial growth of a consecutive crop (Řídký 1976, Ellis et al. 1979, Harper 1989).

The unfavourable effect of straw on germination, emergence and tillering of winter wheat was stated by Smallfield (1992). It resulted in grain yield reduction, particularly where there was shallow straw incorporation into soil. The increasing depth of incorporation abated this unfavourable effect.

Graham et al. (1986) recorded decreasing yields of winter crops if straw remained on the soil surface in comparison with burned straw. The incorporation of straw reduced its negative effect on yields, however, the yields were lower than after straw burning.

Lower yields of winter wheat continuous cropping after shallow straw incorporation into soil in comparison with ploughing were reported by Prew and Lord (1988).

In experiments aimed at the effect of different practices of straw management on the yield of winter wheat continuous cropping, positive effects of straw burning and acceleration of straw decomposition using organo-mineral fertilizers (based on beet molasses stillage) were found (Procházková and Dovrtěl 2000).

The results obtained from the evaluation of long-term effects of different forms of organic amendment on yields and yield trends of winter wheat continuous cropping in our experiments demonstrate pronounced positive effects of straw burning and green manuring and adverse effects of annual straw incorporation into soil. These effects increased in the course of time. Favourable effects of straw burning and green manuring on yields of winter wheat continuous cropping can be related to their phytosanitary effects and reduction of inhibition effects of straw and post-harvest residues, in green manuring also with positive effects on the soil environment.

The effect of different organic amendment on the content of oxidable carbon and humus substances was evaluated in the experiment. The results are presented by Procházka (1986) and Procházková et al. (2001). Nine to 11 years after the experiment establishment, the content of organic carbon was almost identical in all variants. The evaluations performed after 26 to 28 years showed a slight increase in both the content of oxidable carbon and humus substances in variants with green manuring, straw incorporation into soil and farmyard manuring. However, the differences between the variants were small. It is in accordance with the finding that the dynamic balance of soil organic matter needs a couple of decades to constitute (Kubát 1999).

In general, the results of evaluating the effects of different organic amendment on yields of winter wheat continuous cropping suggest a possibility of a higher concentration of cereals in the sugar-beet chernozem production region. However, the winter wheat continuous cropping system should be considered as an extreme form of specialization even under the presented conditions. The favourable effect on yields of winter wheat continuous cropping was found in straw burning and growing intercrops for green manuring. Annual straw incorporation into soil showed a negative effect on grain yields under drier and warmer conditions of the sugar-beet production region. It deepened over time, however, it can be compensated for by supporting straw decomposition using special organo-mineral fertilizers, for instance, on the basis of beet molasses stillage.

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ABSTRAKT

Vliv různého organického hnojení na výnosy ozimé pšenice pěstované v dlouhodobé monokultuře

Pokusy probíhaly na černozemní půdě v řepařské výrobní oblasti v letech 1971–2002. Bylo hodnoceno šest variant organického hnojení (l – sklizeň slámy, 2 – sklizeň slámy + zelené hnojení, 3 – zaorávání slámy, 4 – zaorávání slámy + zelené hnojení, 5 – pálení slámy, 6 – do roku 1977 pálení slámy + meziplodina, od roku 1978 zaorávání chlévského hnoje (10 t/ha). Vliv organického hnojení na výnosy ozimé pšenice pěstované v monokultuře byl statisticky průkazný. V průměru za celé pokusné období (32 let) byly dosaženy vyšší výnosy na variantách s pálením slámy (var. 5) – 6,04 t/ha a se zeleným hnojením (var. 2) – 6,03 t/ha a nižší výnosy na variantách se zapravováním slámy do půdy (var. 3) – 5,65 t/ha, (var. 4) – 5,67 t/ha. Nejmenší rozdíly mezi variantami byly zaznamenány v první dekádě pokusu. S postupem času (ve druhé a ve třetí dekádě pokusu) se rozdíly zvětšovaly a docházelo ke zvyšování příznivého vlivu zeleného hnojení a pálení slámy a nepříznivého vlivu zapravování slámy do půdy. Výnosová úroveň ozimé pšenice pěstované v dlouhodobé monokultuře byla v daných podmínkách vysoká. Průměrný výnos za celé období pokusu byl 5,85 t/ha, v první dekádě 5,19 t/ha, v druhé dekádě 6,54 t/ha a ve třetí dekádě pokusu 5,76 t/ha.

Klíčová slova: ozimá pšenice; dlouhodobá monokultura; hospodaření se slámou; zelené hnojení; hnojení chlévským hnojem; výnos zrna

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