EFFECT OF CONTINUOUS CROPPING ON YIELDS AND SOIL FERTILITY FROM 1941 TO 1980 AT BROOKINGS

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ABSTRACT

Crop yields are controlled in large part by climate, mainly seasonal precipitation amounts, and by fertility levels. Additions of fertilizer increase water use efficiency and increase yields in most years. Average yields, over a number of years, for wheat, oats, rye, barley, and corn were increased, respectively, about 6, 20, 14, 15, and 15 bushels per acre by fertilization. Fertilization with phosphorus (P) increased soil total P, Bray P, and NaCl P but decreased soil pH. The total nitrogen (N) of the unfertilized plot soils decreased 29% from 1942 to 1976, and moderate N fertilizer applications did not increase the amount significantly. The soil N and Bray P amounts in 1941 likely are lower than the amounts originally present in the uncultivated soil. In 1908 on the same farm and soil series as the present study, total N was reported as 6335 lbs acre^{-1} and total P was 1330 lbs acre^{-1}. In contrast, the amounts found in 1976 were 3400 lbs N acre^{-1} and 920 lbs P acre^{-1}. Fertilization at recommended rates can increase crop yields without increasing the content of fertilizer elements in the soil above amounts in the uncultivated soil.

The purpose of this paper is to summarize 40 years of research by various investigators on plots planted continuously to wheat, oats, rye, barley, or corn without applications of fertilizer and chemicals. What are the effects on crop yields and soil fertility? The plots were part of a large study on soil management (Puhr, 1962) that was discontinued in 1961, but the continuously cropped plots were maintained for another 20 years. Half of each plot was fertilized from 1959 through 1980 to compare crop yields and soil fertility in fertilized and unfertilized plots.

Long-term crop rotations and soil management systems have been evaluated for yields and soil fertility at a number of locations (Mitchell et al., 1991). Studies were initiated in 1843 at Rothamsted, England (Allison, 1943), in 1876 at the Morrow plots in Illinois (DeTurk, et al, 1927; DeTurk, 1938), and in 1888 at the Sanborn Field in Missouri (Smith, 1942; Woodruff, 1949). In general, soil organic matter and nitrogen (N) decrease with continuous cropping but rotations with legumes and/or applying manure or crop residues can reduce the rate of decrease or maintain the amounts in the soil. Phosphorus (P) can limit yields after crops have removed the reserves that accumulated in the uncultivated soil.

METHODS

Three replications of 28 x 52 foot field plots on Vienna silt loam were planted continuously to wheat, oats, rye, barley, sorghum, and corn from 1942 through 1980. In 1959, the plots were divided and half of each plot was fertilized. Corn received 60 lbs (N) acre^{-1} and 40 lbs P_2O_5 acre^{-1} annually and small grain received 40 lbs N and 40 lbs P_2O_5 per acre^{-1} annually. Grain yields were collected by Puhr from 1941 to 1961 and by the Soil Testing Laboratory in 1978 and 1980. Soil analyses of the plow layer (0 to 7 inches) were by Puhr (1962) for 1941 and 1958, by the Soil Testing Laboratory for 1968, 1971, and 1980, and by the author for 1976. Analyses in 1976 were: total nitrogen—Kjeldahl, organic matter—Walkley-Black, available potassium--ammonium acetate extraction and flame photometer, total phosphorus--perchloric acid digestion and ascorbic acid colorimetric procedure, available phosphorus—Bray weak acid method or by extraction with 0.1 N NaCl, and pH—glass electrode procedure.

Results

Average yields from fertilized plots were higher than from unfertilized ones (Table 1). Small grain yields from unfertilized plots were similar in the 1942-58 and 1959-80 periods, but corn yields were larger in the second period when hybrid corn was planted. Precipitation was low from September 1958 to May 1959 (Table 2), but summer precipitation was sufficient so that corn yields were larger from fertilized than from unfertilized plots. Corn plants per acre in the fertilized plots may not have been great enough to use above-average summer precipitation water. Average corn yields (1959-80) were about 15 lbs acre^{-1} higher from fertilized plots than unfertilized ones.

Hutton (1933) reported results of a 20-year study (1908-1927) of a corn-oats-wheat-barley-red clover rotation with or without various combinations of NPK fertilization. These plots were located about 0.1 mile from Puhr's plots

Table 1. Crop yields (bu/acre) from fertilized (F) and unfertilized (U) plots that were continuously cropped.

	CROP									
Harvest	**Wheat**		**Oats**		**Rye**		**Barley**		**Corn**	
Years	U	F	U	F	U	F	U	F	U	F
Av. 42-58	19	-	50	-	27	-	34	-	45	-
1959	9	6	26	22	12	17	15	15	35	50
1960	30	30	51	78	33	48	47	56	54	63
1961	16	21	52	71	28	39	27	49	55	71
1978	32	44	41	64	23	49	34	51	65	76
1980	21	37	46	81	29	41	38	62	88	103
5 yr. av.	22	28	43	63	25	39	32	47	59	74

Table 2. September through August precipitation at Brookings that affect the 1959, 60, 61, 78, and 80 crop yields.

	CROP YEAR				
	1959	**1960**	**1961**	**978**	**1980**
			inches/month		
Sept.	1.91	2.10	2.64	3.70	1.40
Oct.	0.13	2.59	0.55	2.34	1.97
Nov.	0.97	0.60	0.88	1.49	0.38
Dec.	0.10	0.62	1.22	0.73	0.00
Jan.	0.23	0.32	0.12	0.15	0.13
Feb.	0.36	0.04	0.23	0.00	0.41
March	0.00	0.97	0.54	0.75	0.53
April	0.32	3.00	0.97	3.77	0.34
May	6.81	3.26	6.00	4.17	1.09
June	2.43	4.73	4.64	2.89	9.28
July	1.60	1.49	2.03	4.03	2.58
Aug.	3.06	6.98	5.52	2.25	3.93

on the same soil type. Average yields from six unfertilized and two NPK-fertilized plots were, respectively, for corn—34 and 42, wheat—14 and 17, oats—35 and 36, barley—29 and 39 bu acre^{-1} or for red clover—806 and 1315 lbs acre—. Average yields in the 1933 study are in the lower part of the range reported in Table 1 for the unfertilized continuously cropped plots during the 1959-80 period. In 1908, total soil nitrogen and phosphorus were, respectively, 6335 and 1330 lbs acre^{-1} in the plow layer. The fertility probably was higher in the earlier study because the area had been farmed only a few years. Thus, fertilization increased yields less in the Hutton study than in this study.

The soil analyses in 1976 (Table 3) for the unfertilized and fertilized plots, averaged across the six crops, were significantly different for total P, NaCl P, and Bray P. The applied P fertilizer had increased the amount readily available to plants as measured by the NaCl- and Bray-P methods. The addition of fertilizer decreased soil pH (Table 3), probably because nitrogen fertilizers characteristically decrease soil pH. Soil pH was also lower in fertilized compared to unfertilized plots in 1968, 1971, and 1980 (Table 4). Fertilized soils tended to have higher average organic matter contents than the unfertilized ones (Table 3), but the difference was significant only in 1980 (Table 4). Fertilizer increases root growth as well as top growth. Corn and sorghum plots may have the least organic matter (Table 3) because these plots were cultivated. Small grains were not cultivated and have many fibrous roots which grow in the plow layer.

The average total P of the unfertilized and fertilized plots in 1976 was 460 and 549 ppm, respectively, or a difference of 89 ppm P (Table 3). Forty

Table 3. Soil differences in unfertilized (U) and fertilized (F) plots used for corn, sorghum, oats, wheat, barley, or rye in 1976.[§]

Soil Properties	Corn U	Corn F	Sorghum U	Sorghum F	Oats U	Oats F	Wheat U	Wheat F	Barley U	Barley F	Rye U	Rye F	PROPERTY AVERAGE U	PROPERTY AVERAGE F
	CROP													
pH	6.8	6.6†	6.7	6.3†	6.8	6.5†	6.8	6.4	7.0	6.9	6.7	6.5	6.8	6.5**
Total N—%	0.16	0.16	0.15	0.16	0.17	0.19*	0.18	0.18	0.18	0.18	0.19	0.20	0.17	0.18
Bray P—ppm#	18	37*	14	41**	10	40*	11	41**	28	20	7	37**	15	36*
NaCl P—ppm	1.0	2.5†	0.4	2.8*	0.3	2.8*	0.4	3.2*	1.1	2.2	0.4	3.9*	0.6	2.9**
Total P—ppm	382	510†	400	515	458	564**	575	534	530	531	478	638*	460	549**
Organic matter %	3.1	3.1	2.9	3.0	3.6	3.6	3.4	3.5*	3.5	3.4	3.9	4.0	3.4	3.5

[§] Plots were not fertilized from 1942 to 1958, and half of each plot was fertilized after 1958. Means for U and F significantly different at, † $p < 0.1$, * $p < 0.05$ and ** $p < 0.01$.
1 ppm equals 2 pounds/acre

Table 4. Average properties of the continuous crop plots that were unfertilized (U) or fertilized (F).

Year	Organic Matter % U	Organic Matter % F	Bray P lbs/acre U	Bray P lbs/acre F	Potassium lbs/acre U	Potassium lbs/acre F	Nitrogen lbs/acre U	Nitrogen lbs/acre F	pH U	pH F
	SOIL MATERIAL†									
1941	-	-	109	-	-	-	4790	-	-	-
1958	-	-	29	-	-	-	3920	-	-	-
1968	2.7	2.7	19	50**	181	184	-	-	6.8	6.6**
1971	3.0	3.1	31	66**	219	217	-	-	6.9	6.6**
1976	3.4	3.5	29	72*	-	-	3400	3600	6.8	6.5*
1980	2.3	2.5**	32	69**	322	312	-	-	7.1	6.9**

† Data for 1941 and 1958 from Puhr (1962): 1968 and 1971 unpublished data by Quentin Kingsley and Soil Testing, SDSU: 1980 data from Soil Testing,SDSU.
** Means for U and F significantly different at $p < 0.01$.
* Means for U and F significantly different at $p < 0.05$.

pounds of P_2O_5 fertilizer is equivalent to 8.7 ppm P in the plow layer, assuming the soil weighs 2 million pounds. From 1958 to 1976, 157 ppm P was added. The 89 ppm P divided by 18 years is about 4.9 ppm P per year that was not removed by the crops. Puhr (1962) reported the soil available P (i.e. Bray P) in 1941 and 1962 was, respectively, for corn plots, 107 and 33 lbs acre^{-1} and for sorghum plots, 122 and 28 lbs acre^{-1}. The Bray P in 1976 (Table 3) for unfertilized and fertilized plots was, respectively, 18 and 37 ppm (36 and 75 lbs acre^{-1}) for corn and 14 and 41 ppm (28 and 82 lbs acre^{-1}) for sorghum. Thus, the unfertilized plots in 1962 and 1976 had approximately the same amount of available P but the fertilized plots had about two

times more available P in 1976. However, the amount reported in 1941 was 109 lbs acre^{-1} so the fertilization rate was not large enough to increase the amount to the 1941 available P level.

The average total N content of the soils in the unfertilized plots was 4790, 3920, and 3400 lbs acre^{-1}, respectively, in 1941, 1958, and 1976 (Table 3). The decrease in soil N was 51 lbs/acre/year during the 1941-1958 period and 29 lbs/acre/year during the 1958-1976 period. Hutton (1933) had reported 6335 pounds/acre in his plot soils in 1908. If this value is correct for Puhr's plots, the loss of N was 47 lbs/acre/year from 1908 to 1941. Loss of N from 1908 to 1941 and from 1941 to 1976 was approximately the same. The N contents of the unfertilized and fertilized plot soils in 1976 were not significantly different. Fertilization has not replenished the N lost in cultivation.

Soil nitrogen and organic matter are closely related because much of the nitrogen is incorporated into organic matter as microbes decompose plant tissue. Differences reported in Table 4 for organic matter from one year to others probably result from differences in laboratory procedures, because differences between fertilized and unfertilized soils are similar from year to year. The average soil has about 20 times more organic matter than nitrogen. In 1976, the soils in unfertilized plots had 20 times more organic matter than nitrogen. If the relationship was correct in 1908 and 1941, the organic matter contents would have been, respectively, 6.3 and 4.8 percent.

Grain yields are usually greater from fertilized plots than from unfertilized ones even in years with below-average precipitation. Fertilizer applied at recommended rates would not increase the nitrogen and phosphorus to amounts greater than were in the pristine prairie soils.

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