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EFFECT OF NITROGEN ON CROP YIELD AS INFLUENCED BY SOIL pH AND FERTILIZATION WITH FARMYARD MANURE

DZIAŁANIE AZOTU NA PLONOWANIE ROŚLIN W ZALEŻNOŚCI OD ODCZYNU GLEBY ORAZ NAWOŻENIA OBORNIKIEM

Abstract: At the Experimental Station of the Agriculture and Biology Department of Warsaw University of Life Sciences in Skierniewice fertilization experiments have been carried out continuously since 1923, in which the effects of lime, nitrogen, phosphorus, potassium and farmyard manure are studied in a static system with rotation of a few crops. Farmyard manure has been applied on a very acidic soil with a pH of about 4, and on a slightly acidic soil with a pH of 6.0–6.5. This paper describes only the results from combinations with and without nitrogen fertilization in the fields without FYM (since 1923) and with FYM (since 1992). The results presented here include the mean for 4 years yields of potatoes (fertilized with FYM) and grain crops grown in successive years following farmyard manure applications. Included are also the most important properties of the soils sampled in the last year after treatments with farmyard manure.

Yield increases resulting from nitrogen fertilization were very high and generally higher in the fields without manure than those with manure. The presence of farmyard manure was found to increase the organic carbon content and total nitrogen content in the soil by about 10 %. This type of fertilizer caused higher increases in yield in the combinations without nitrogen fertilization than in those involving applications of nitrogen.

Keywords: yield, long-term fertilizer experiment, soil organic carbon, forms of soil nitrogen

The utilization of nitrogen from nitrogen fertilizers generally fluctuates in the range of 55–65 %, but often the effect of that component is worse, which due to the high prices of such fertilizers makes their use less cost-effective. Good results with nitrogen are mainly achieved not only in favourable climatic conditions, but also in

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soil conditions that are best-suited to the requirements of a given plant species. For that reason, nitrogen can be expected to produce good results if the soil has not been excessively depleted of humus and is not strongly acidified. The influence of these factors on the effectiveness of nitrogen can best be seen in long-term experiments [1–5].

The authors of this paper have at their disposal the results of long-term fertilization experiments, in which the effect of nitrogen on various crop plants has been studied over many years. The studies have been carried out on both strongly and weakly acidic soils, on which there have been no applications of farmyard manure since 1923, or in the fields where fertilization with FYM began in 1992. An assessment of the effects of these factors on the yields of a few species of crop plants and on the most important soil properties from theoretical and practical points of view seemed to be very interesting.

Materials and methods

At the Experimental Station of the Agricultural and Biology Department of Warsaw University of Life Science in Skierniewice, fertilization experiments have been carried out continuously since 1923, in which the effects of lime, nitrogen, phosphorus, potassium and farmyard manure are studied in a static system with rotation of a few crops. The experiments are conducted in 21 fields, where the total number of experimental plots (~50 m^2 each) is 650. This paper describes only the results from the combinations with and without nitrogen fertilization in those fields where crops are grown, without papilionaceous plants and without manure. The experiments are carried out on a podsolic soil containing 15–17 % of leachable components in the Ap horizon (0–25 cm) and 25 % in the B and C horizons. For the purpose of this study, 4 fields were chosen, including 2 fields with a very acidic soil (pH about 4), and 2 fields with a weakly acidic soil (pH 6.0–6.5). In one field with the very acidic soil, and in one field with the weakly acidic soil, fertilization with farmyard manure began in 1992 and continued every 4 years at a rate of 30 Mg · ha^{-1}. By 2008 there had been four applications of manure for growing potato, and the next year, after the potato crop, cultivation included spring triticale, oat and rye on the very acidic soil, and spring barley, mustard and triticale on the weakly acidic soil. The results presented here are 2-year average yields. Over the period of 85 years, the application rates of mineral fertilizers increased from N-30, P-13, K-25 kg · ha^{-1} to N-90, P-26, K-91 kg · ha^{-1} from 1976. The fields with the weakly acidic soil are limed every 4 years at a rate of 1.6 Mg CaO per ha. In the fields with the very acidic soil, lime had been applied only five times over the 85-year-long period at a rate of 0.8 Mg CaO per ha. From the experimental plots described above soil samples were taken in the last year after farmyard manure application to determine: pH_{KCl}, hydrolytic acidity (Kappen's method), organic carbon (dry distillation), total nitrogen (Kjeldahl's method), and mineral nitrogen ($N\text{-}NH_4$ + + $N\text{-}NO_3$) in 0.1 mol $CaCl_2$.

Results and discussion

As had been expected, the extent of soil acidification depended mainly on lime application, and to a lesser degree also on nitrogen fertilization (Table 1). The soil of the plots limed only occasionally with small doses during 85 years is very acidic with a very high hydrolytic acidity (37 mmol $H^+ \cdot kg^{-1}$). With regular application of lime every 4 years, the value of soil pH fluctuated in the range of 5.5–6.5, depending on the year after liming, with hydrolytic acidity of 10–15 mmol $H^+ \cdot kg^{-1}$. Regular applications of ammonium nitrate also resulted in soil acidification. For example, on the plots without liming and without nitrogen fertilization, soil pH is higher by about 0.6, and hydrolytic acidity lower by about 12 mmol $H^+ \cdot kg^{-1}$ than on the plots fertilized with nitrogen. A somewhat smaller effect of nitrogen fertilization on soil acidification was obtained on limed plots. A small reduction in soil acidification was also obtained on farmyard manure plots. The acidifying effect of nitrogenous fertilizers and the mitigating effect of farmyard manure on soil acidification were also reported by other authors [2, 6–9].

Humus content in the soil depended mainly on the fertilization with farmyard manure, and also on nitrogen fertilization and liming. The highest increase in the organic C content in the soil resulting from four applications of manure since 1992 was obtained on the very acidic soil fertilized with nitrogen (Table 1). By taking into account an average increase in $C_{org.}$ due to FYM (0.41 $g \cdot kg^{-1}$) and the carbon dose in the manure (~16 $Mg \cdot ha^{-1}$), it was possible to calculate that about 10 % of the carbon from the manure was found in the soil. In other experiments on the same soil, but lasting much longer, the humification coefficient was within the 6–8 % range [3, 10, 11]. Only in short-term experiments, much more C_{org} from manure could be found in the soil [6, 7].

Table 1

Soil properties at the last year after FYM application depending on long-term fertilization

Soil properties	FYM since 1992	Fertilization since 1923			
		PK	NPK	CaPK	CaNPK
pH	O	4.5	3.9	6.5	6.1
	FYM	4.8	4.1	6.6	6.3
Hh [$mmol \cdot kg^{-1}$]	O	25.8	37.5	10.8	11.6
	FYM	24.5	37.7	12.2	14.5
C organic [$g \cdot kg^{-1}$]	O	3.91	4.51	4.22	4.62
	FYM	4.19	5.04	4.60	5.08
N total [$g \cdot kg^{-1}$]	O	0.35	0.43	0.38	0.45
	FYM	0.40	0.49	0.41	0.48
N mineral [$mg \cdot kg^{-1}$]	O	41.5	40.2	42.3	52.1
	FYM	48.6	51.6	48.5	63.5
C:N	O	11.2	10.5	11.1	10.3
	FYM	10.5	10.3	11.2	10.6

Hh – hydrolytic acidity.

With the passing of time from the last manure application, less and less $C_{org.}$ from that FYM, fertilizer remains in the soil. What needs to be emphasized, however, is the fact that nitrogen fertilization had an even greater effect on $C_{org.}$ content in the soil than farmyard manure. The plots fertilized with ammonium nitrate had higher levels of C_{org} in the soil by on average of 0.57 g · kg^{-1}, with the increase being as much as 0.67 g · kg^{-1} in the very acidic soil. This means that fertilization with nitrogen considerably increased the yields of crop biomass, including the yields of post-harvest crop residue. The smallest effect on C_{org} increase in the soil was that of liming, on average by only 0.22 g · kg^{-1}. This may have been due to the fact that, as the available literature indicates, liming contributes to the mineralization of humus.

The ratio of carbon to nitrogen in the soil was similar for all the experimental combinations. This indicates that the direction of the changes in total N in the soil, as affected by the factors studied, was very much like that of the $C_{org.}$ changes.

The differences in mineral nitrogen content ($N\text{-}NH_4$ + $N\text{-}NO_3$) in the soil were greater than those in total nitrogen. In all the combinations with FYM, the levels of mineral nitrogen were higher (Table 1). Lime applications also increased mineral N content in the soil, but only on the plots fertilized with nitrogen. Nitrogen fertilization also increased mineral N content in the soil, but only in the limed field. As is evident from the available literature, the mineral nitrogen content in the soil depends not only on the factors listed above [12–17], but also, and perhaps above all, on the time during the growing season when the soil samples are taken for analysis [13, 18].

The yields of plants grown on the soil fertilized with neither nitrogenous fertilizers nor manure for dozens of years were very low – about 9 Mg · ha^{-1} of potato tubers and 1.0–1.5 Mg · ha^{-1} of grain from cereals (Table 2). At such yields, the uptake of nitrogen from the soil did not exceed 30 kg N · ha^{-1}, and these amounts of nitrogen could have come from atmospheric precipitation and the activity of free-living bacteria. Similar rates of nitrogen uptake from the soil in combinations which had not been fertilized with nitrogen were obtained in other experiments [11, 16, 19]. Farmyard manure used in amounts similar to the national average rate (7.5 Mg · ha^{-1} annually) increased the yields of potato tubers to 15 Mg · ha^{-1} and the yields of cereal grains to 1.2–2.0 Mg · ha^{-1}. These results indicate the levels of yielding that we should expect if we continue to cultivate crops for a long period of time without mineral fertilizers. To obtain higher yields on such farms, papilionaceous plants would have to be included in crop rotation.

Very low yields of spring triticale were obtained on the plots without nitrogen fertilization and that is why the increases in yield influenced by this component, in the limed field, were the highest. In the other grain crops, the effect of nitrogen was also large. The yields from the plots fertilized with nitrogen were more than twice as high as those from the plots without nitrogen fertilization. What can also be noted is that the effect of nitrogen was in most cases higher in the field without FYM than in the manured field. The yield-enhancing effect of manure was dependent not only on nitrogen fertilization but also on soil acidity and the species of the cultivated plant. The increases in the yields of almost all the crop plants (except potatoes and spring triticale on the acidic soil) influenced by manure on the plots without nitrogen were higher than on the plots fertilized with nitrogen. The relationship for potatoes and spring triticale is greater in limed fields than on a very acidic soil. The literature [8, 9, 20] says that the yield-enhancing effect of nitrogen will be significant only if the growth of plants is not inhibited by strong acidification of the soil.

Table 2

Yield of plants depending on long-term fertilization and manuring (FYM) on the limed and unlimed soils (mean of 4 years)

Plants	Fertilization since 1923	$Mg \cdot ha^{-1}$		%, CaPK, PK =100		FYM increased %
		–FYM	+FYM	–FYM	+FYM	
Potato	PK	5.51	9.29	100	100	68.6
	NPK	7.12	12.54	129.2	135.0	76.1
	CaPK	8.7	16.5	100	100	89.7
	CaNPK	19.1	23.6	219.5	143.0	23.6
	LSD	0.49	0.52			
Spring triticale	PK	0.93	1.16	100	100	24.7
	NPK	1.22	1.69	131.2	145.7	38.5
	CaPK	0.96	1.34	100	100	39.6
	CaNPK	3.12	3.14	325.0	324.3	0.6
	LSD	0.21	0.23			
Oat	PK	1.21	1.85	100	100	52.9
	NPK	3.34	3.70	279.0	200	10.8
	LSD	0.19	0.24			
Rye	PK	1.52	2.02	100	100	32.9
	NPK	3.89	4.26	255.9	210.9	9.5
	LSD	0.25	0.27			
Spring barley	CaPK	1.35	2.03	100	100	50.4
	CaNPK	2.91	3.56	215.6	175.4	22.3
	LSD	0.24	0.27			
Mustard	CaPK	0.57	0.85	100	100	49.1
	CaNPK	1.58	2.00	277.2	235.3	26.7
	LSD	0.17	0.21			

$LSD_{(0.05)}$ – only for N fertilization.

The soil of the plots without nitrogen fertilization (PK and CaPK) is sufficiently rich in available forms of phosphorus and potassium, and thus it can be inferred that the effect of farmyard manure may be dependent mainly on a good supply of nitrogen to plants. In comparison with the effect of nitrogen from mineral fertilizers, the after-effect of the nitrogen from manure is also greater, especially of that applied for many years. This is demonstrated by the fact that in the last year after the application of manure there is more total and mineral nitrogen in the manured than non-manured field (Table 1).

Conclusions

1. Applications, of farmyard manure, every four years, increased organic carbon and total nitrogen content by about 10 %.

2. Ammonium nitrate used over many years reduced soil pH and increased hydrolytic acidity of the soil.

3. Yield increases influenced by nitrogen fertilization were very high and in most cases higher on the non-manured than manured plots.

4. The effect of farmyard manure on crop yield was in most cases greater on the plots without rather than with nitrogen fertilization.

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DZIAŁANIE AZOTU NA PLONOWANIE ROŚLIN W ZALEŻNOŚCI OD ODCZYNU GLEBY ORAZ NAWOŻENIA OBORNIKIEM

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Abstrakt: W Stacji Doświadczalnej Wydziału Rolnictwa i Biologii SGGW w Skierniewicach nieprzerwanie od 1923 r. prowadzone są doświadczenia nawozowe, gdzie bada się działanie wapna, azotu, fosforu, potasu i obornika w układzie statycznym w kilku zmianowaniach roślin. Obornik stosuje się na glebie bardzo kwaśnej o pH około 4 oraz słabo kwaśnej o pH 6,0–6,5. W niniejszej pracy zamieszczono wyniki badań uzyskane tylko z obiektów nawożonych i nienawożonych azotem, na polach bez obornika (od 1923 r.) i z obornikiem (od 1992 r.). Uzyskane dane obejmują średnie z 4 lat plony ziemniaków (nawożonych obornikiem) oraz plony roślin zbożowych uprawianych w kolejnych latach po oborniku. Zamieszczono również najważniejsze właściwości gleb pobranych w ostatnim roku po oborniku.

Zwyżki plonów pod wpływem nawożenia azotem były bardzo duże i przeważnie większe na polach bez obornika niż z obornikiem. Obornik zwiększał zawartość węgla organicznego i azotu ogólnego w glebie o około 10 %. Nawóz ten bardziej zwiększał plony na obiektach nienawożonych azotem niż na kombinacjach, gdzie stosowano ten składnik.

Słowa kluczowe: wieloletnie doświadczenia nawozowe, plony roślin, węgiel organiczny, formy azotu w glebie