Electronic Journal of Polish Agricultural Universities is the very first Polish scientific journal published exclusively on the Internet, founded on January 1, 1998 by the following agricultural universities and higher schools of agriculture: University of Technology and Agriculture of Bydgoszcz, Agricultural University of Cracow, Agricultural University of Lublin, Agricultural University of Poznan, Higher School of Agriculture and Teacher Training Siedlce, Agricultural University of Szczecin, and Agricultural University of Wroclaw.

ELECTRONIC
JOURNAL
OF POLISH
AGRICULTURAL
UNIVERSITIES

2000
Volume 3
Issue 2
Series
AGRONOMY

KRUCZEK A. 2000. IMPACT OF VARIED SOIL NITROGEN RICHNESS ON THE EFFECTIVENESS OF CORN FERTILISATION WITH NITROGEN **Electronic Journal of Polish Agricultural Universities**, Agronomy, Volume 3, Issue 2.
Available Online http://www.ejpau.media.pl

IMPACT OF VARIED SOIL NITROGEN RICHNESS ON THE EFFECTIVENESS OF CORN FERTILISATION WITH NITROGEN

Andrzej Kruczek
Department of Land and Plant Cultivation, Agricultural University in Poznań, Poland

ABSTRACT

The research defined the effectiveness of corn fertilisation with nitrogen depending on its content in soil and covered N uptake, agronomical and physiological fertilisation efficiency as well as coefficients of nitrogen-fertliser utilisation. Spring and autumn doses were defined which were applied to balance N fertilisation and uptake by plants as well as the degree of N utilisation from the same doses applied in autumn and spring. As for the plant dry matter yield, the agronomical and physiological efficiency of all the spring N doses at 160 and 240 kg·ha^{-1} introduced into the soil in autumn were negative, and the coefficient of nitrogen utilisation against other fertilisers did not exceed 7.4%.

Key words: corn, nitrogen fertilisation, nitrogen fertilisation efficiency, autumn doses, spring doses

INTRODUCTION

Numerous research conducted both at home [1,11,13,14,15] and abroad [3,10] show that the nitrogen activity is seen not only over the year it was applied but also as a post-effect. According to those authors, yield increases as a post-effect range from several to several dozen %, depending on the plant species. The effectiveness of the nitrogen post-effect also depends on the weather conditions, especially rainfall, as well as soil type and the forecrop, which is confirmed by Van der Pauuv [10] and Stumpe [12] who show low post-N effects over years with a low winter rainfall.

The present research aimed at defining nitrogen fertilisation effectiveness at varied N soil richness with some fertilisation efficiency indicators.

MATERIAL AND METHODS

The present research included 1992-1994 strict field experiments carried out at Swadzim near Poznań. A two-factor experiment was conducted as a split-plot with four replications. Four autumn fertilisation doses constituted the first factor, 0, 80, 160 and 240 $kg \cdot ha^{-1}$ of N, treated as a way to differentiate the mineral nitrogen soil richness. Nitrogen was applied over late autumn to avoid the temperature which would allow nitrification. The second factor represented N doses applied once in spring immediately prior to corn sowing at the respective amounts of 0, 40, 80, 120 and 160 $kg \cdot ha^{-1}$. Nitrogen fertilisers both times were applied as carbamide – $CO(NH_4)_2$. The phosphorus fertilisation level in all the objects remained the same - 44 $kg \cdot ha^{-1}$ and potassium - 132.8 $kg \cdot ha^{-1}$.

The experiments were conducted on lessive light-clayey-sandy soil, light clayey top-subsoil, of the good rye soil suitability complex, IVa soil classification class. The soils ranged in their potassium content from medium to very high (9.5-17.3 mg K per 100 g of soil), high to very high phosphorus content (7.2-9.8 mg P per 100 g of soil), and soil reaction from pH=5.3 in 1M KCl in 1992 to pH=6.0 in 1994. The experiment investigated a hybrid, 'Melina' (FAO 220) bred by Pioneer. Over all the research years winter rape constituted a forecrop.

The research period showed varied weather conditions (Table 1). The semi-dry period over the total growing season of 1992 and high air temperature showed a negative effect on the corn development and yielding. Even in August (64.0 mm) – the month when the total rainfall was higher than that of the total research years (58.1 mm), a considerable rainfall (43.6 mm) was recorded as late as the third decade. 1994, despite its total vegetation period rainfall being higher than the total rainfall over the research-years of the same period, showed an unfavourable rainfall distribution for corn. Over the critical period (corn flowering and grain filling) there was observed a considerable soil moisture deficit at high air temperature. The vegetation period of 1993 recorded some very high rainfall, higher than the mean for the research years from April to September by 150 mm. However the year was chilly, which is seen from June-September air temperature monthly means lower than the multi-year values by 1.5-1.9 °C. The total October-March rainfall was higher than the value for the research years (197.3 mm) and over 1991/1992 amounted to 230.8 mm, over 1992/1993 - 213.9 mm and over 1993/1994 - 281.8 mm.

Table 1. Weather conditions at Swadzim

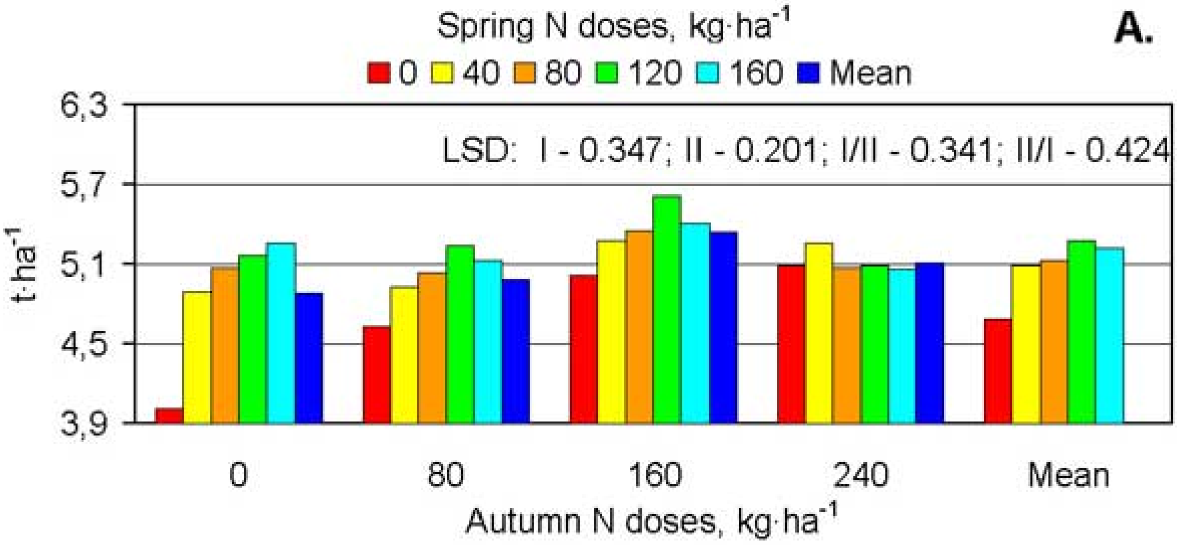
	Years									
Months	1991	1992	1993	1994	1958-1994	1991	1992	1993	1994	1958-1994
	Air temperature, °C					Rainfall, mm				
I	-	-0.9	0.6	2.5	-1.7	-	15.1	53.4	50.4	31.0
II	-	2.1	-0.5	-2.6	-1.0	-	30.5	36.9	18.5	22.7
III	-	3.3	2.6	4.5	2.7	-	89.6	27.4	67.1	29.4
IV	-	7.6	9.6	9.1	7.6	-	20.1	8.6	47.5	33.6
V	-	13.9	16.4	12.0	13.1	-	37.1	86.6	66.4	51.0
VI	-	19.3	15.0	15.9	16.5	-	3.0	80.4	34.3	59.3
VII	-	20.0	16.1	21.9	18.0	-	26.6	135.9	63.5	69.9
VIII	-	20.8	15.8	17.9	17.4	-	64.0	69.2	54.2	58.1
IX	-	13.1	11.9	13.3	13.4	-	14.8	64.9	55.1	42.7
X	7.8	5.6	7.8	6.3	8.6	31.6	29.3	18.5	21.4	37.4
XI	3.4	3.9	-0.4	4.2	3.6	32.0	36.9	34.9	34.2	36.3
XII	-0.2	-0.6	2.2	2.2	0.0	32.0	30.0	92.4	50.3	40.5
Mean/Sum	-	9.0	8.1	8.9	8.2	-	-	-	-	-
X-III	-	-	-	-	-	-	397.0	709.1	562.9	511.9

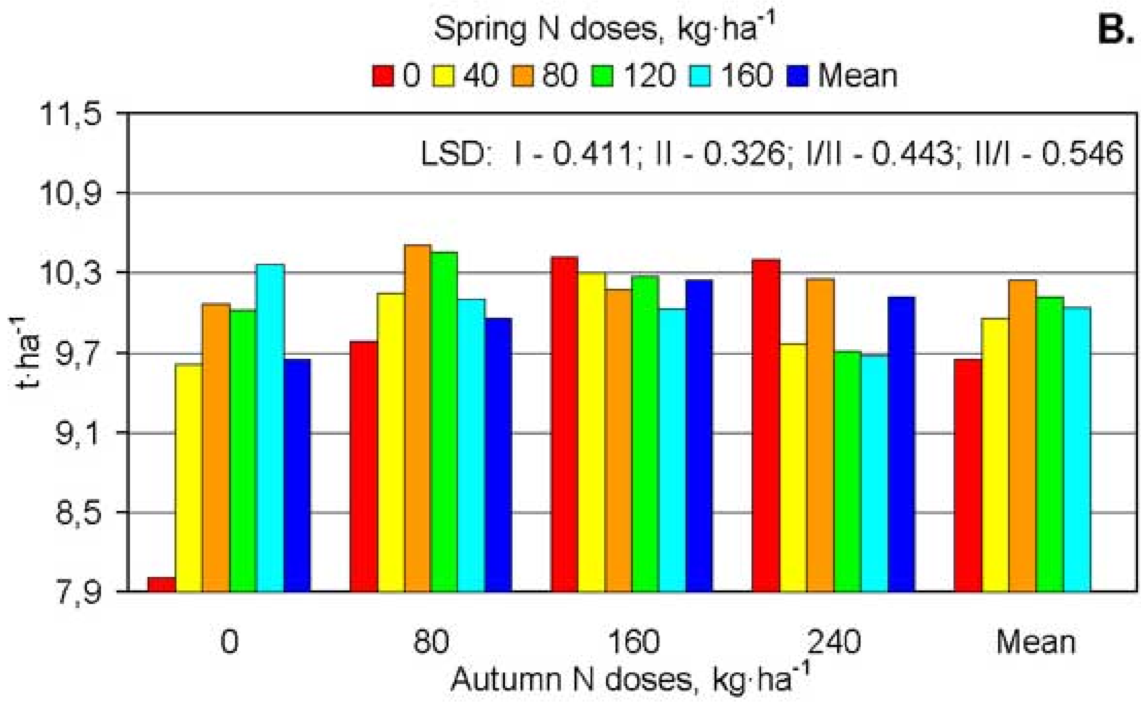
RESULTS

Nitrogen doses applied in autumn and spring showed a significant impact on both the grain yield and the corn dry matter yield (Fig. 1). There was also observed a co-effect of autumn and spring fertilisation which was visible as a decrease in the effect spring doses with an increase in autumn doses. The object non-fertilised in autumn showed that the grain and plant dry matter yields increased with an increase in spring N dose up to 160 kg·ha^{-1}. The autumn application of 80 or 160 kg·ha^{-1} of N increased the grain yields up to the N spring dose of 120 kg·ha^{-1}, yet the 160 kg·ha^{-1} of N autumn application resulted in a much higher corn yielding.

PRINT

Fig. 1. Grain (A) and dry matter (B) yields





At 240 kg N·ha^{-1} applied in autumn corn did not react to spring fertilisation. Following the N autumn application of 80 kg·ha^{-1}, plant dry matter yields increased up to the N spring dose of 80 kg·ha^{-1}. Autumn-applied 160 kg·ha^{-1} of N decreased the yield with each spring nitrogen dose. There was observed a considerable post-effect of nitrogen application, not for the forecrop – winter rape, but after its harvest. With no spring fertilisation it was reflected in an increase in grain yields by 27%, and an increase in the yield of plant dry matter by 30%.

An impact of nitrogen fertilisation on the nitrogen uptake by corn was similar to the impact on the grain and the plant dry matter yields (Fig. 2 and Table 2). As for the grain yield, when no nitrogen was applied over autumn, the nitrogen uptake increased with an increase in spring nitrogen doses, yet over 40 kg·ha^{-1} of N, no significant differences were noted. A similar nitrogen effect in objects non-fertilised in autumn was observed for N uptake with plant dry

PRINT

matter yield, yet no significant differences in N uptake were observed for the spring N dose exceeding 80 kg·ha^{-1}. Introducing N into the soil in autumn at the doses of 80 and 160 kg·ha^{-1} increased the N uptake with the grain yield up to the spring N dose of 120 kg·ha^{-1}. However the autumn N dose of 160 kg·ha^{-1} increased the nitrogen uptake. As for corn dry matter yield, an autumn N application of 80 kg·ha^{-1} increased nitrogen uptake only up to the N dose of 80 kg·ha^{-1} applied in spring. At higher autumn N doses, 160 and 240 kg·ha^{-1}, the spring nitrogen application did not increase its uptake with the whole plant yield, and an autumn N dose of 240 kg·ha^{-1} – also with the grain yield.

Fig. 2. Grain-yield-N uptake

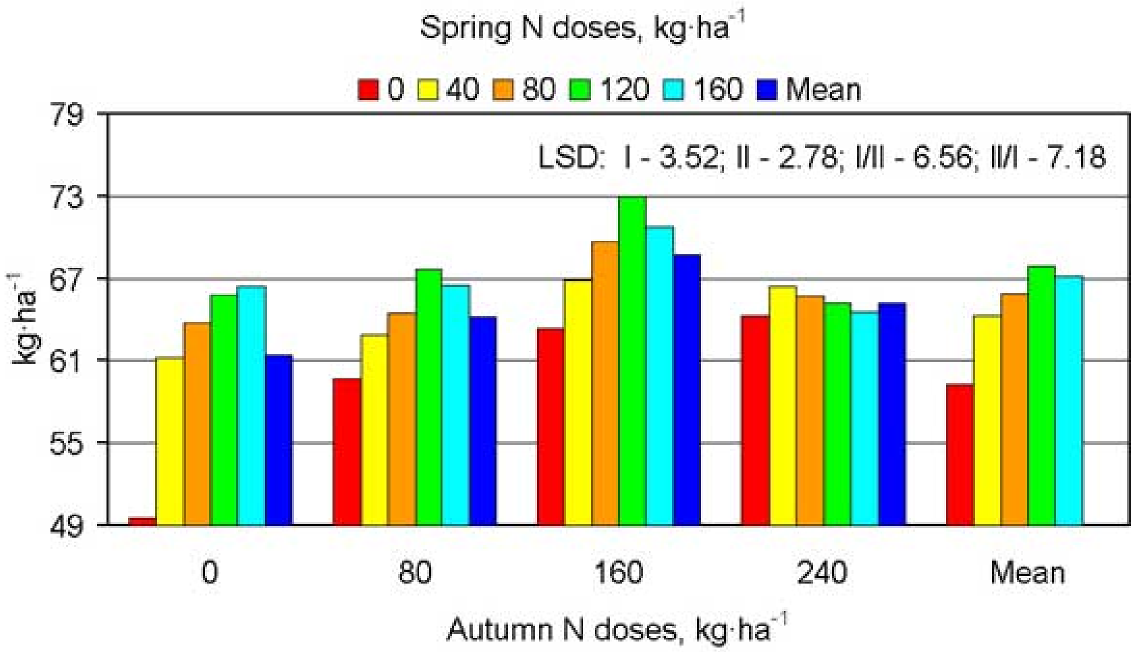


Table 2. Dry matter N uptake

Spring N doses kg·ha^{-1}	Autumn N doses, kg·ha^{-1}											Mean N uptake
	0		80			160			240			
	N uptake	Balance difference (dose - uptake	N uptake	Balance difference (dose-uptake)		N uptake	Balance difference (dose-uptake)		N uptake	Balance difference (dose-uptake)		
				Spring dose	Total dose		Spring dose	Total dose		Spring dose	Total dose	
	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}	kg·ha^{-1}
0	93.3	-93.3	119.3	-119.3	-39.3	127.6	-127.6	+32.4	128.8	-128.8	+111.2	117.3
40	112.9	-72.9	125.8	-85.8	-8.8	130.2	-90.2	+69.8	129.1	-89.1	+150.9	124.5
80	121.1	-41.1	132.9	-52.9	+27.1	133.5	-53.5	+106.5	129.4	-49.4	+190.6	129.2
120	124.3	-4.3	131.4	-11.4	+68.6	130.3	-10.3	+189.7	129.8	-9.8	+230.2	128.9
160	127.8	+32.2	125.6	+34.4	+114.4	130.0	+30.0	+190.0	129.6	+30.4	+270.4	128.3
Mean	115.9	-	127.0	-	-	130.3	-	-	129.3	-	-	-
$NIR_{0.05}$	for autumn doses = 8.01 for spring doses = 5.63 for interaction between autumn doses (I) and spring doses (II) – I/II = 11.26; II/I = 12.87											

Table 2 presents a mineral nitrogen balance suggested in papers on nitrogen transformation and plant utilisation [4,8,16]. The input was represented by N doses applied, and the output - N uptake with plant dry matter yield. Such a simplified balance considers neither nitrogen losses nor increasing soil richness in nitrogen due to mineralisation. The results obtained show that balancing the nitrogen uptake with an exclusive spring fertilisation, irrespective of the amount of N introduced into soil in autumn, took place with the same N dose of about 120 kg·ha^{-1}. Considering the total amount of N applied in autumn and spring fertilisers, balancing the doses with the uptake took place as early as with the first autumn N dose of 80 kg·ha^{-1} and the spring dose lower than 40 kg·ha^{-1}. A detailed calculation of the balanced dose was made with square regression, with independent variable being the nitrogen dose, and the dependent variable – the nitrogen balance coefficient, namely the ratio of N uptake to its fertiliser dose. If the balance coefficient = 1, the fertilisation and uptake are balanced. The N balance doses obtained from regression equations are presented in Table 3. If only the spring N fertilisation equals uptake, the N dose balanced was similar for all the autumn N fertilisation and ranged from 115 to 119.6 kg·ha^{-1}. However when considering the total N fertilisation it turned out that to balance the lowest autumn N dose of 80 kg·ha^{-1}, it is enough to apply in spring only 22 kg·ha^{-1} of N. Greater nitrogen dose introduced into soil in autumn were themselves higher than the nitrogen doses uptaken by corn.

Table 3. Nitrogen doses balanced, kg·ha^{-1} (N uptake – N dose)

Autumn doses kg·ha^{-1}	Doses balanced with	
	Spring N fertilising only	Total nitrogen fertilising
0	115.0	115.0
80	119.6	22.1
160	118.9	-
240	116.3	-

Agronomical efficiency reflects the fertilisation efficiency and expresses an increase in the yield per fertiliser nitrogen unit. Physiological efficiency reflects not only the effect of the application of mineral fertiliser nitrogen but also soil reserve nitrogen and measures fertilisation physiological efficiency which defines a plant capacity to transform the nitrogen uptaken into agricultural yield. Such capacity is defined with the yield increase per plant uptake nitrogen unit. In the present research both indicators of fertilisation efficiency have been calculated for agricultural yields for corn – dry matter yield of the total overground plant biomass and grain yield (Tables 4 and 5). As for the grain yield, the agronomical and physiological efficiency were positive for all the nitrogen doses applied in spring whenever there was no autumn fertilisation, or with autumn N doses of 80 and 160 kg·ha^{-1}. Autumn N fertilisation with 240 kg·ha^{-1} showed that over the spring N dose of 80 kg·ha^{-1} the agronomical and physiological efficiency were negative. It can be concluded therefore that the amounts of nitrogen uptake doses were not used by corn to increase the grain yield. However the plant dry matter yield, the agronomical and physiological efficiency were positive for all the spring doses, whenever there was no autumn fertilisation, or when the lowest N dose of 80 kg·ha^{-1} was applied. Spring attempts to apply nitrogen fertilisation, following the autumn N soil fertilisation with 160 or 240 kg·ha^{-1}, made both kinds of fertilisation efficiency negative, therefore the nitrogen uptake doses did not affect the total corn dry matter yield.

Table 4. Agricultural production effectiveness for corn nitrogen fertilisation

Spring N doses kg·ha⁻¹	Grain				Plants			
	Autumn N doses, kg·ha^{-1}				Autumn N doses, kg·ha^{-1}			
	0	80	160	240	0	80	160	240
	kg of grain per 1 kg fertiliser N				kg of dry matter per 1 kg of fertiliser N			
40	18.6	6.5	5.6	3.5	39.9	9.0	negative	negative
80	11.2	4.3	3.5	negative	25.8	9.0	negative	negative
120	8.2	4.4	4.2	negative	16.7	5.6	negative	negative
160	6.6	2.7	2.1	negative	14.7	1.9	negative	negative

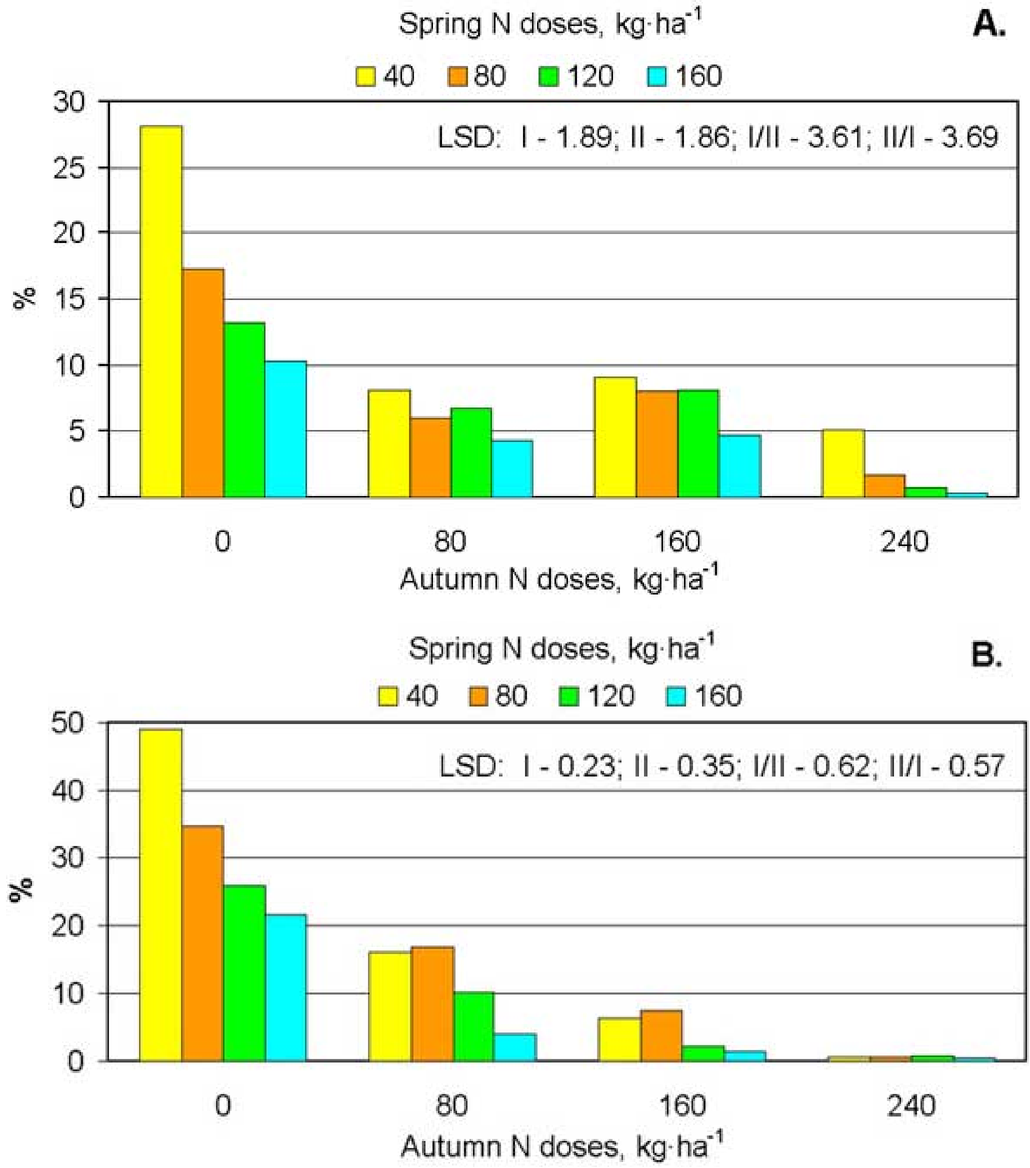
Table 5. Physiological effectiveness of corn N uptake

Spring doses of N	Grain				Plants			
	Autumn N doses, kg·ha^{-1}				Autumn N doses, kg·ha^{-1}			
	0	80	160	240	0	80	160	240
	kg of grain per 1 kg of uptake N				kg of dry matter per 1 kg of uptake N			
40	66.3	80.9	61.3	68.9	81.4	55.6	negative	negative
80	65.0	71.7	43.8	negative	74.1	53.4	negative	negative
120	62.6	64.7	51.9	negative	64.9	55.7	negative	negative
160	64.4	63.4	44.3	negative	68.2	49.1	negative	negative

The degree of mineral fertiliser N utilisation which reflects the plant nitrogen uptake efficiency has been calculated as the quotient of agronomical to physiological efficiency. Nitrogen uptake of all the spring doses decreased with an increase in autumn fertiliser doses, which was due to an increase in autumn fertiliser nitrogen reserves (Fig. 3). Such regularity was observed for coefficients of nitrogen uptake for grain and for plant yields. Grain yield nitrogen utilisation decreased from 28.1% for 40 kg·ha^{-1} of N applied in spring and without autumn N fertilisation to 0.3% for spring N dose of 160 kg·ha^{-1} and autumn N dose of 240 kg·ha^{-1}. Similarly the coefficient of plant dry matter nitrogen utilisation decreased from 49% to 0.5%.

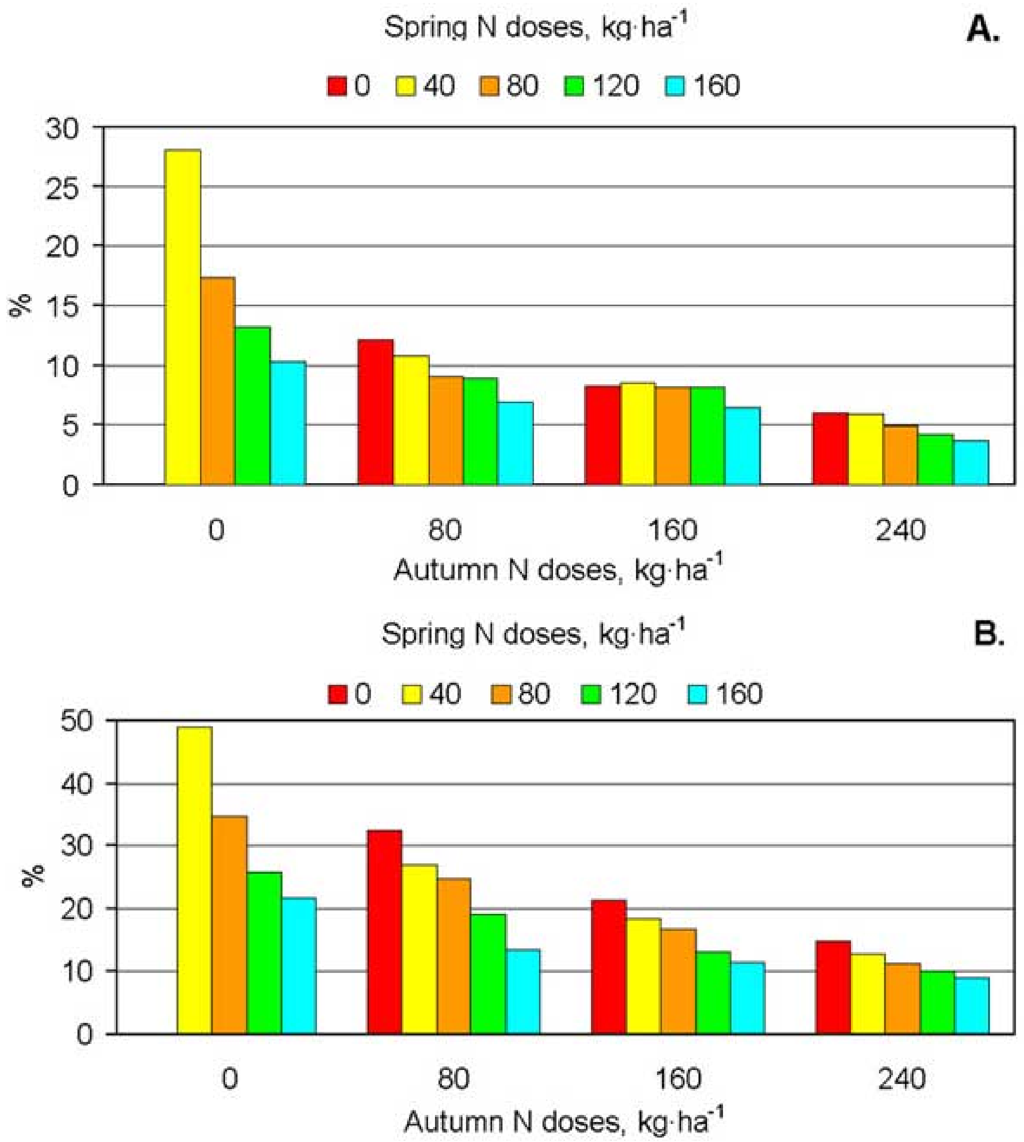
PRINT

Fig. 3. Spring N-fertiliser grain-yield (A) and plant-yield (B) N consumption



A total autumn and spring dose nitrogen utilisation showed that the spring nitrogen dose utilisation was greater than the autumn nitrogen utilisation when the same doses were applied (Fig. 4). The difference decreased with the increase in the comparable doses and mostly referred to the coefficients of N utilisation calculated for the grain yield than for the plant dry matter yield. The utilisation for the grain yield of 80 $kg \cdot ha^{-1}$ of N applied in spring amounted to 17.3%, and that applied in autumn - 12.1%, while 160 $kg \cdot ha^{-1}$ – 10.3% and 8.3%, respectively (Fig. 4A). As for the corn dry matter, the N utilisation from the 80 $kg \cdot ha^{-1}$ applied in spring amounted to 34.8%, while that applied in autumn – 32.5% (Fig. 4B). At the higher fertilisation level of N - 160 $kg \cdot ha^{-1}$, the difference was practically inconsiderable as the N fertiliser utilisation coefficient decreased from 21.6% for the spring application to 21.4% for autumn fertilisation. Such inconsiderable differences in the utilisation of N applied over different periods and interrupted by winter show that N introduced into soil in late autumn when the temperature exclude or considerably limit nitrification, did not show greater losses from soil. Decreases in the values of N utilisation coefficient from spring doses due to an increase in autumn fertilisation were greater than those of autumn doses due to the spring fertilisation.

Fig. 4. Autumn-and-spring N-fertiliser grain-yield (A) and plant-yield (B) N consumption



DISCUSSION

Diversifying the amount of nitrogen in soil through a late-autumn carbamide application defined the effectiveness of spring nitrogen doses with selected fertilisation efficiency indicators: grain yields and the yields of the overground corn biomass, nitrogen uptake with grain yield and plant dry matter yield, agronomical efficiency and physiological efficiency as well as fertiliser N utilisation. In the present research the efficiency of spring fertilisation decreased with an increase in soil richness in N, namely increasing doses of nitrogen applied in autumn. The non-autumn-N-fertilised object, both the grain yield and the plant dry matter

PRINT

yield increased up to the highest spring N dose of 160 kg·ha^{-1}. Yield increases for the N dose range of 0-160 kg·ha^{-1} amounted to 1.25 tonnes of grain and 2.36 tonnes of plant dry matter per ha. Analysing the results obtained one can say that growing corn for grain yield – the optimum spring N dose ranged from 80 to 120 kg·ha^{-1}, with the nitrogen soil richness affected by autumn N fertiliser of 0-160 kg· ha^{-1}.

However as for the harvest of the total overground biomass, corn yielded highest after the N spring application of 160 kg·ha^{-1} with no autumn fertilisation, or a spring N dose of 80 kg·ha^{-1} at N autumn application of 80 kg·ha^{-1}. As for greater soil richness in nitrogen due to autumn fertilisation with the doses of 160 and 240 kg·ha^{-1} of N, spring doses were not effective, which had been confirmed by earlier research of the author [6], especially for grain yield. The average optimal N dose defined with the multinomial and non- continuous function, for corn cultivated for grain amounted to 90 kg·ha^{-1}, and for corn cultivated for silage of 150 kg·ha^{-1}. A similar result was recorded by Fotyma [2] who defined the optimal N dose for corn cultivated for silage, both on lighter and heavier soils as 150 kg·ha^{-1}.

In case of no autumn fertilisation, N uptake in the present research increased with an increase in the N spring dose up to 160 kg· ha^{-1}, however the difference in the corn grain N uptake over 40 kg·ha^{-1} and corn plant N uptake over 80 kg·ha^{-1} remained insignificant. In his earlier research [5,7], the author presented on the relationships between N fertiliser doses and N uptake as regression equations 2^{o}, for full corn maturity, for 3-4-leaf and for panicle-flowering phases. In the present research the greatest total yield N uptake (206.5 kg N per 1 ha) was observed for corn pre-sowing fertilised with 240 kg·ha^{-1} of N. However the nitrogen uptake in the earlier reports for N-free control amounted to 115.7 kg N per ha, average for N doses <100 kg·ha^{-1} – 151.8 kg N per ha, for 100-200 kg·ha^{-1} – 186.6 kg N per ha, and for doses >200 kg·ha^{-1} – 196.3 kg N per ha. As reported by Szmigiel [14] the amount of corn nitrogen uptake increased with an increase in N fertilisation, yet non-proportionally to the N dose.

The present research recorded no increase in the dry matter corn yield, both for 1 kg of fertiliser N and for 1 kg of plant uptake N, for all the spring N doses with 160 and 240 kg·ha^{-1} applied in autumn. No increases in corn grain yield (negative agronomical and physiological efficiency), was observed only for spring N doses over 80 kg·ha^{-1} applied along with autumn 240 kg·ha^{-1} of N. The author's earlier grain yield reports [6] revealed a negative agronomical and physiological efficiency over 90 kg·ha^{-1} of N. However negative plant yield efficiency was observed only for 2-fold higher N doses - 180 kg·ha^{-1}. An increase in dry matter per 1 kg of fertiliser N decreased from 38.6 kg for N doses <100 kg·ha^{-1} to 12 kg for N doses >200 kg· ha^{-1}, while an increase in dry matter per 1 kg of uptake N from 59.7 kg for N doses <100 kg·ha^{-1} to 32.4 kg for N doses >200 kg·ha^{-1} [5]. Fotyma [2] showed that the agronomical and physiological efficiency did not depend on the fertilisation level exclusively, but also on the soil; which held true especially for agronomical efficiency. As for N doses of 0-210 kg·ha^{-1}, agronomical efficiency decreased from 34.3 to 8.0 kg of dry matter per 1 kg of N on light soil and from 47.5 to 10.1 kg of dry matter per 1 kg of N on heavy soil, while physiological efficiency from 70.1 to 24.7 kg of dry matter per 1 kg of uptake N and from 71.3 to 24.2 kg of dry matter per 1 kg of uptake N. Similarly in the present research the fertilisation efficiency decreased with an increase in spring and autumn doses and the variation in physiological efficiency was much lower than in agronomical efficiency, which shows a slight variation in the N fertiliser-induced N transformation. The differences between agronomical efficiency and physiological efficiency remained relatively high, which on the one hand shows a low fertiliser-N-consumption potential, and on the other hand – a high efficiency in the N-into-grain yield transformation.

In the present research, N consumption by corn grain and by the plant itself decreased with an increase in fertiliser N dose. The results obtained comply with the literary reports. According to Nielsen et al. [9], most frequently fertiliser nitrogen uptake under field conditions amounts to 40-60% [5,7]. The earlier research with pre-sowing corn fertiliser doses from 0 to 270 kg·ha^{-1} of N showed a decrease in N consumption coefficient from 71.2% for 30 kg·ha^{-1} of N to 28.7% for 270 kg· ha^{-1} of N. A similar result was reported by Fotyma [2], for N doses of 0-210 kg·ha^{-1} the coefficients of N utilisation on rye-complex soils ranged from 50 to 30%, while on wheat-complex soils – from 70% to 40%.

CONCLUSIONS

1. Efficiency of pre-sowing nitrogen doses, expressed both as an increase in grain yield and dry matter yield decreased with an increase in soil richness in N due to autumn fertilisation.
2. No matter if N was applied in autumn or not, N uptake was balanced by N spring fertilisation for the dose of 117.4 kg·ha^{-1}. In order to balance the fertilisation by N uptake, following the lowest dose of 80 kg· ha^{-1} of N, the spring N dose of 22 kg· ha^{-1} turned out sufficient. Higher autumn N doses of 160 and 240 kg·ha^{-1} exceeded the amount of corn N uptake.
3. Grain yield increases per 1 kg of fertiliser N as well as uptake N were noted for all the spring doses, both for no autumn N fertilisation and for autumn N doses of 80 and 160 kg·ha^{-1}. Plant yield increases were recorded only for all the spring doses and for the lowest autumn N dose - 80 kg· ha^{-1}. Agronomical and physiological fertilisation efficiency were then positive and decreased with an increase in spring N doses.
4. N losses from soil dated back to late autumn fertilising were scarce, which was seen from little or no differences in the consumption of N per parallel spring and autumn doses.

REFERENCES

1. Dembiński F., 1975. Rośliny oleiste. PWRiL Warszawa.
2. Fotyma E., 1994. Reakcja roślin uprawy polowej na nawożenie azotem. III. Kukurydza. Fragm. Agron. 4 (44), 20-35.
3. Herron G.M., Terman G.L., Dreier A.F., Olson R.A., 1968. Residual nitrate nitrogen in fertilised deep loess-derived soils. Agron. J. 60, 477-482.
4. Jankowiak J., 1991. Efektywność produkcyjna i ekonomiczna oraz optymalizacja nawożenia azotem pszenicy ozimej i ziemniaka w zależności od deszczowania. IUNG Puławy, R (282), 113.
5. Kruczek A., 1999. Effectiveness of nitrogen fertilising of maize depending on dose and environmental factors. Scientific Papers of Agricultural University of Poznań, Agriculture 1, 37-50.
6. Kruczek A., 1997. Efektywność nawożenia azotem kukurydzy uprawianej na ziarno w rejonie Wielkopolski. Rocz. Nauk Rol. 112A (3-4), 183-198.
7. Kruczek A., 1997. Wpływ nawożenia azotowego na pobieranie azotu przez kukurydzę i zmiany jego zawartości w glebie. PTPN, Wydz. Nauk Rol. i Leśnych 83, 69-80.
8. Müller S., Görlitz H., 1990. Wykorzystanie metody N_{min} w NRD. Fragm. Agron. 1, 23-35.
9. Nielsen N.E., Schjoring J.K., Jensen H.E., 1988. Efficiency of fertiliser uptake by spring barley. In: Nitrogen efficiency in agricultural soil. Eds. S. Jenkinson and A.A. Smith. Elsevier Appl. Sci., London, 62-72.
10. Pauuv F., van der, 1963. Residual effect of nitrogen fertiliser on succeeding crops in modedose marine climate. Plant and Soil XIX (3), 324-331.
11. Praca zbiorowa: Nawożenie. Red. R. Czuba. 1979. PWRiL, Warszawa.
12. Stumpe H., 1980. Einfluss des Vorfruchtertrages und der Beregnung der Vorfrucht auf die im Boden-verbleibenden Mengen anorganischen Stickstoff. Arch. Acker u. Pflanzenbau u. Bodenkde, 24 (4), 233-240.
13. Szmigiel A., 1981. Następcze działanie nawozów azotowych. Cz. I: Wpływ następczy saletry amonowej zastosowanej pod buraki cukrowe na plonowanie jęczmienia jarego. Acta Agraria et Silvestria, s. Agraria. PAN – Oddz. w Krakowie, Kom. Nauk Rol. i Leśnych. XX, 239-249.
14. Szmigiel A., 1982. Następcze działanie nawozów azotowych. Cz. II: Wpływ saletry amonowej zastosowanej pod rzepak ozimy i kukurydzę na plonowanie pszenicy ozimej. Acta Agraria et Silvestria, s. Agraria, PAN – Oddz. w Krakowie, Kom. Nauk Rol. i Leśnych. XXI, 123-138.
15. Szmigiel A., 1989. Badania nad plonowaniem roślin i wykorzystaniem azotu w zbożowym członie zmianowania na tle dawki i sposobu nawożenia. Zesz. Nauk. AR Kraków, Rozpr. habil. 131.
16. Wagenet R.J., Miller R.W., 1979. Nitrogen a key to plant growth. Utah Sci. 40 (1), 4-7.

Submited:

Andrzej Kruczek
Department of Land and Plant Cultivation
Agricultural University in Poznań
Mazowiecka 45/46, 60-623 Poznań, Poland
Phone: (4861) 8487515
e-mail: kruczek@au.poznan.pl
