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Effect of Fertilization System and NO_3-N Distribution on Corn Yield

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The objectives of the study have been to determine the effects of winter precipitation, NO_3-N distribution in the soil profile and their interaction on corn yield in different fertilization systems. Corn yield varied across fertilization systems and winter rainfall in the investigated years (2001–2004). Significantly higher yields were found in variants with manure application in diculture (DC-M-NPK – 12.11 t ha^{-1}) and in monoculture (MC-M-NPK – 9.25 t ha^{-1}). Path coefficients showed that the highest direct positive effects on corn yields were exhibited by NO_3-N amounts at soil depths 30–60 cm and 60–90 cm (p = 0.4336** and p = 0.2346**, respectively). Winter precipitation had a direct negative effect on the yield performance (p = –0.1159), however, the downward movement of NO_3-N from topsoil (0–30 cm) to deeper soil layers (30–60 and 60–90 cm), whose N levels were directly positively correlated with yield, made the indirect effect of winter precipitation on yield positive.

Keywords: corn, grain yield, fertilizing system, NO_3-N, rainfall, path coefficients

Introduction

Corn yield depends on a large number of factors and interactions among them. Key factors are the amount and distribution of rainfall during growing season and crop management, especially fertilization system and crop rotation (Tabatabai et al. 1992; Senwo and Tabatabai 2005; Hoffmann et al. 2007; Seremesic et al. 2008). Huzsvay and Nagy (2005) maintain that corn yield is primarily affected by sunlight, temperature, available plant nutrients and water supply. In three long-term rotation experiments, Doll (1962) found that 20–23% of the deviations of yields from the linear regression across years could be attributed to winter precipitation. The level of nitrate nitrogen in agricultural lands depends on soil type, method of land utilization, system of soil cultivation used, temperature, moisture and air content (Starčević et al. 2003; Rosolem et al. 2005). Also, Izsáki and Iványi (2005) found that harmful environmental side-effects of N over-fertilization can be avoided by determining the mineral N pool of the soil and the N requirements of the cultivated crop. Nitrate nitrogen status in the soil changes with the ascending and descending movements

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of soil water. The dynamics of nitrate nitrogen is considerably affected by the application of fertilizers, both organic and mineral.

The basic assumption from which we started in this study was that winter precipitation significantly affects the dynamics and movement of mineral nitrogen in soil and that NO_3-N levels in various soil layers in the spring (before corn planting) directly affect corn yield. Taking in consideration the dynamics of corn growth, depth of root system penetration into the soil and differences in nutrient uptake from different soil layers, it was assumed that the studied parameters and their interaction would affect corn yield performance, the knowledge of which could be useful for optimizing corn fertilization practices.

Materials and Methods

The effect of fertilization system, winter rainfall and NO_3-N distribution in the soil profile on corn yields was studied in a long-term stationary field trial established in 1965 at the Rimski Sancevi Experimental station (N 45° 19', E 19° 50') of the Institute of Field and Vegetable Crops in Novi Sad, Serbia. A part of the trial included corn monoculture, and another part a two-crop rotation of corn and spring barley. The soil in the experimental plots is classified as calcareous chernozem on loess substrate. Its humus content was 2.74%, the contents of total nitrogen, available P_2O_5 and K_2O were 0.15%, 23.6 mg and 26.8 mg per 100 g of soil, respectively.

The following fertilization variants were used in monoculture (MC): control (Ø); MC-NPK – mineral fertilizers only (130 N : 70 P_2O_5 : 70 K_2O); NPK + corn stalks (MC-S-NPK); NPK + manure (MC-M-NPK). The variant DC-M-NPK (NPK + manure) was used in the two-crop rotation of corn and spring barley. In the variant DC-M-NPK, spring barley was sown only as a preceding crop for corn, was not fertilized and was only used to monitor the prolonged effect of the fertilizers used for corn. In the part of the trial in which corn was grown in two-crop rotation, manure was applied each year under corn at the rate of 25 t ha^{-1}. In the monoculture, manure was applied at two-year intervals, at the same rate. In all years, corn was machine planted at the stand density of 57,000 plants per hectare and at the optimum sowing date in Serbia (05–25 April). Three hybrids of the FAO maturity group 600 were used. No specific crop protection measures, except the chemical treatment against corn root worm were used on plots sown with corn monoculture.

Average yield of the hybrids per fertilization variants are presented in this paper. For determination of mineral nitrogen, soil samples were taken from 30-cm layers to the depth of 120 cm. The samples were analyzed by the method developed by Scharpf and Wehrmann (1975). This paper presents mineral nitrogen levels in soil samples taken before planting. Grain yield per hectare was calculated on 14% moisture basis and expressed in t ha^{-1}. The paper deals with the results obtained in the period 2001–2004. The data were evaluated by the Least Significant Difference test (LSD 0.05 and 0.01) and the correlation analyses using statistical software Statistica 7.1. Path analysis (using Systat 11) was used to partition the relative contribution of yield determining components via standardized partial regression coefficients, i.e. to separate the correlation coefficients into the direct and indirect influences.

Weather conditions

A review of the monthly temperatures and rainfall in the studied four-year period showed that these parameters varied significantly from one year to another as well as that some values differed significantly from long-term averages (Table 1). For example, the year of 2002 had a considerably higher average annual temperature (12.9°C) than the long-term average (1964–2004). Variations were especially evident regarding precipitation level, both in the winter period (October–March) and during the growing season (April–September). Considering the average annual values, 2001 was extremely humid, 2004 was humid, while 2002 and 2003 were extremely dry. In the last two years, the annual precipitation was lower than the long-term average (618 mm) by 201 and 156 mm, respectively.

Results

In the spring before planting, total NO_3-N content in soil highly varied (Fig. 1), in dependence of fertilization system and year. The highest NO_3-N level (201.5 kg ha^{-1} on average for all variants) was found in 2003. The variants with the highest NO_3-N levels in that year were MC-M-NPK and DC-M-NPK, 294.19 and 289.85 kg ha^{-1}, respectively. In the other years, the NO_3-N levels were significantly higher in the variants that combined organic and mineral fertilizers than in the control and the variants in which only mineral NPK were applied.

Furthermore, NO_3-N level differed significantly among soil depths. On average for all years and fertilization systems, the highest NO_3-N levels were found in the soil layers 30–60 and 60–90 cm (49.60 and 45.28 kg ha^{-1}, respectively), the lowest values having been found in the control and the NPK variant.

On average for all fertilization systems under study, highly significant correlations were found for the NO_3-N levels per soil layer and total amount of winter precipitation (Table 2). The highest positive correlation was registered for the layer 90–120 cm (r = 0.88**), but those for the layers 30–60 and 60–90 cm were also positive and highly significant. A highly significant negative correlation (r = –0.73**) was registered for the layer 0–30 cm, which was a consequence of downward movement of nitrates under the effect of winter precipitation. Correlations varied slightly within the individual fertilization systems with the exception of the control variant for which it was not possible to find a close relationship between precipitation and NO_3-N level.

The analysis of variance for grain yield of corn (Table 3) indicated that there existed highly significant effects of fertilization system, year and their interaction ($P < 0.001$) on yield. The highest yields were obtained in the manured variants DC-M-NPK and MC-M-NPK, 12.11 t ha^{-1} and 9.25 t ha^{-1}, respectively. A comparison of these two variants showed that the crop rotation (spring barley/corn) improved corn yield performance across the 4-year study period by 2.86 t ha^{-1} in relation to corn monoculture.

The highest average yield (10.31 t ha^{-1}) was obtained in 2003. That year had a considerably lower annual precipitation sum (462 mm) than 2001 and 2004, lower by 156 mm than the long-term average for the studied site (Table 1).

Table 1. Precipitation and temperature conditions at Rimski Šančevi experimental station (N 45° 19', E 19° 50')

Year		Month												VP*	W**	Yearly
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII			(1.10–30.09)
	2001	3.5	4.4	11.0	11.2	17.8	18.3	22.3	22.7	16.1	14.9	4.3	–3.2	18.1	–	11.9
t	2002	0.2	7.3	9.0	11.7	18.1	21.8	23.6	22.2	17.1	12.9	10.2	0.8	19.1	–	12.9
(°C)	2003	–1.4	–4.8	6.0	10.9	20.6	24.0	22.6	24.6	17.2	10.3	8.4	2.5	20.0	–	11.7
	2004	–1.0	2.4	6.8	12.4	15.2	19.8	22.0	21.7	16.3	14.3	7.0	2.7	17.9	–	11.6
	LTA	–0.4	1.7	6.3	11.5	16.9	19.9	21.5	21.0	16.8	11.6	6.0	1.3	17.9	–	11.2
	2001	38	27	73	127	75	233	56	30	162	14	70	15	683	219	902
P	2002	8	25	11	26	87	27	33	55	46	90	24	33	274	143	417
(mm)	2003	48	22	9	8	23	31	60	30	84	142	27	18	236	226	462
	2004	54	41	16	112	89	97	63	39	42	89	139	33	442	298	740
	LTA	38	33	38	47	59	86	68	60	47	47	51	48	361	254	618

* VP – Growing season (IV–IX); ** W – Winter precipitation (X–III), *** LTA – Long-term averages (1964–2004)

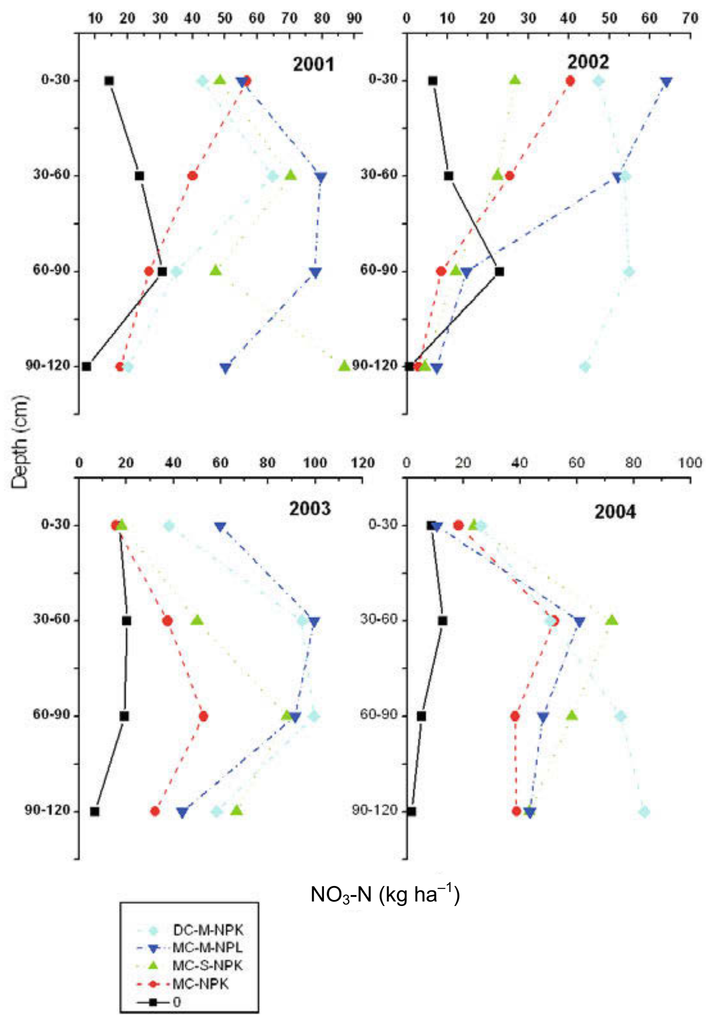

Figure 1. Spring soil NO_3-N level (kg ha^{-1}) in the 0 to 120 cm soil profile at different fertilization variants

Table 2. Correlation coefficients between mineral nitrogen level (per soil layer) and amount of winter precipitation in the different fertilization variants

NO_3-N in layer (cm)	Fertilization variant					Average for all variants
	Ø	MC-NPK	MC-S-NPK	MC-M-NPK	DC-M-NPK	
0–30	+0.20**	–0.50**	–0.13**	–0.87**	–0.95**	–0.73**
30–60	+0.16**	+0.98**	+0.87**	+0.20**	–0.03**	+0.59**
60–90	–0.68**	+0.68**	+0.64**	+0.42**	+0.35**	+0.51**
90–120	+0.15**	+0.93**	+0.45**	+0.76**	+0.63**	+0.88**

* significant at 0.05; ** significant at 0.01 probability level

Table 3. Effects of fertilization system, crop rotation and year on grain yield (t ha^{-1})

Fertilization system	Year				Average
	2001	2002	2003	2004	
Ø	4.52	5.16	7.34	4.18	5.30
MC-NPK	7.95	7.23	9.86	8.27	8.33
MC-S-NPK	8.61	7.74	10.61	8.42	8.85
MC-M-NPK	8.95	7.86	11.50	8.69	9.25
DC-M-NPK	14.50	10.18	12.23	11.54	12.11
Average	8.91	7.63	10.31	8.22	–

Analysis of variance (two-way design)
Variate: Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fertilization system:	4	3.786.304	946.576	365.23	<.001
Year:	3	796.081	265.360	102.39	<.001
Fert. system x year:	12	463.515	38.626	14.90	<.001
Residual	60	155.502	0.2592		
Total	79	5.201.402			

LSD0.05:	Fertilization system:	0.36
	Year:	0.32
	Fertilization system × year:	0.72
LSD0.01:	Fertilization system:	0.48
	Year:	0.42
	Fertilization system × year:	0.96

However, the winter precipitation sum did not differ significantly from the long-term value. The lowest yield (7.63 t ha^{-1}) was obtained in 2002. The annual and winter precipitation sums in that year were considerably lower than the average. It was an indication that further research was necessary on the interaction between winter precipitation sum and soil NO_3-N level. The interaction was subjected to the path coefficient analysis based on r-values and estimated following the procedure of Dewey and Lu (1959).

Table 4 shows the effect of the studied parameters on yield performance calculated via simple correlation coefficients, and Table 5 shows direct and indirect effects of winter precipitation sum (WP) and NO_3-N levels per soil layer on corn yield, calculated via path coefficients. The simple correlation coefficients showed that total soil NO_3-N (r = 0.719** for $NO_{3\text{-NTotal}}$) as well as NO_3-N levels in individual soil layers exhibited highly significant effects on corn yield (Table 4). The highest correlation coefficients were found for the layers 30–60 and 60–90 cm (r = 0.6992** and r = 0.6504**, respectively). When considered

Table 4. Simple correlation coefficients (r) for winter precipitation, NO_3-N levels per soil layers and corn grain yield (on average for all fertilization variants)

	WP	N 0–30	N 30–60	N 60–90	N 90–120	Yield
WP	–	–0.3852**	0.2446*	0.3022**	0.4088**	0.0962^{ns}
NO_3-N (0–30 cm)	–	–	0.5646**	0.1968^{ns}	0.1769^{ns}	0.4008**
NO_3-N (30–60 cm)	–	–	–	0.7887**	0.6715**	0.6992**
NO_3-N (60–90 cm)	–	–	–	–	0.7953**	0.6504**
NO_3-N (90–120 cm)	–	–	–	–	–	0.5642**
NO_3-N_{Total}	0.229*	0.526**	0.932**	0.898**	0.853**	0.719**

* significant at 0.05; ** significant at 0.01 probability level; ^{ns} non-significant

on the basis of its simple correlation coefficient, however, winter precipitation had a non-significant positive effect on yield ($r = 0.0962^{ns}$).

Path coefficients (Table 5) confirmed the relationships between NO_3-N and yield performance obtained on the basis of simple correlation coefficients; the highest direct positive effects on corn yield in the investigated years were exhibited by NO_3-N levels in the soil profiles 30–60 and 60–90 cm (p = 0.4336** and p = 0.2346**, respectively). Based on the path analysis, winter precipitation had a direct negative effect on yield performance (p = –0.1159). Indirectly, however, this effect was negative only via NO_3-N level in the soil layer 0–30 cm; indirect effects of WP via NO_3-N level were positive in deeper soil layers, especially 30–60 and 60–90 cm. Therefore, when NO_3-N moved from the layer 0–30 cm down to the layers 30–60 and 60–90 cm, the indirect effect of winter precipitation also became positive.

Table 5. Matrix of direct and indirect path coefficients (without ridge regression)

Independent variable	Direct effect on yield	Indirect effect on yield via: WP	N 0–30	N 30–60	N 60–90	N 90–120	Total (r_{xy}) Yield
WP	–0.1159**	–	–0.0165	0.1061	0.0709	0.0516	0.0962
NO_3-N (0–30 cm)	0.0428**	+0.0446	–	0.2448	0.0462	0.0223	0.4008
NO_3-N (30–60 cm)	0.4336**	–0.0283	0.0242	–	0.1850	0.0848	0.6992
NO_3-N (60–90 cm)	0.2346**	–0.0350	0.0084	0.3420	–	0.1004	0.6504
NO_3-N (90–120 cm)	0.1263**	–0.0474	0.0076	0.2912	0.1865	–	0.5642

* significant at 0.05; ** significant at 0.01 probability level
R-coefficient of determination = 0.5330
μ – residual effects = 0.6834

The path coefficient analysis indicated that 53.3% of corn yield variability was due to the studied parameters (winter precipitation, sum and NO_3-N level and distribution along soil profile) while 46.7% of the variability was due to other factors.

Discussion

Total spring soil NO_3-N level on experimental plots studied varied significantly depending on fertilization system and year. On the four-year average, the highest NO_3-N level in the soil was found in the variant DC-M-NPK (222.05 kg ha^{-1}) but it was not significant difference in relation to those found in the variants MC-M-NPK and MC-S-NPK. Corn stalks and manure + NPK showed higher NO_3-N levels than those achieved with sole application of mineral fertilizers. Relationship between the variants of fertilizations, distribution of mineral nitrogen along soil profile and the amount of winter precipitation in the same trial had been reported by Starčević et al. (2003). Our results show that the highest average yields achieved in treatments where with the mineral fertilizers applied organic fertilizers. In order to reduce the amount of mineral fertilizers and to minimize the danger of migration of larger quantities of nitrogen out from the root zone, it is recommended to combine mineral fertilizers with manure in corn production.

The highest corn yields were achieved in the variants with combined application of NPK fertilizers with manure and/or incorporation of corn stalks. Rotation of corn with spring barley increased corn yield by 2.86 t ha^{-1} as compared to corn monoculture. This results emphasises the importance of growing corn in crop rotation with simultaneous application of mineral fertilizers combined with manure and/or harvest residues. Most authors reported higher yield and higer amount of NO_3-N in the soil profile when rotating corn with other crops (Berzsenyi et al. 2000; Starčević et al. 2002). Crop rotation can add sustainability to a cropping system by improving yield without increased inputs but by improving soil management (Revees 1997). Latković et al. (2005) obtained the highest corn yields in variants that combined mineral fertilizers and manure. The authors refered that the variants that included manuring required less nitrogen fertilizer for obtaining maximum yields. Plowing under the cornstalks increased the yield by 0.52 t compared with sole application of NPK fertilizers. Also, the NPK variant out yielded the unfertilized variants by the highly significant 3.03 t ha^{-1}. Importance of cornstalks and N fertilization for corn yield and yield stability is discussed by Berzsenyi et al. (2007).

The estimates of correlation and path coefficients can help us to understand the role and relative contribution of various plant traits in establishing growth behaviour of crop cultivars under given environmental conditions (Akhtar et al. 2007). Our results based on the path analysis showed that winter precipitation had a direct negative effect on yield performance. The path coefficient analysis indicated that 53% of corn yield variation was due to the studied parameters (sum of winter precipitation, NO_3-N level and its distribution along soil profile) while the remaining 47% of the variability can be attributed to other factors. Contrary to our results, Marton (2008) obtained high positive correlations between wheat yield and precipitations under different variants of mineral nutrition.

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