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Nitrogen and water use efficiency of maize in long-term field experiment

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Introduction

Maize grown for grain is the third largest cereal crop species in the world. In Poland, since 1990, the sowing area has increased 11 times, reaching 645.4 thous. ha in 2019, which acounts to 11% of the total area under ceral crops. It should be expected, that due to climatic changes, the share of this thermophilic plant in the cropping patterns will be steadily rising in Poland. Maize originating from Mexico, is mainly grown in warmer temperate regions and humic subtropics. It is a C_4 plant, which confers potentially more efficient use of CO_2, solar radiation, water and nitrogen in photosynthesis than C_3 crops. Maize productivity is however largery dependent on nitrogen fertilization at rates that satisfy its needs for this element. At hight yields 14.4 t·ha^{-1} N uptake by the crop reaches 280 kg N·ha^{-1}. Due to the fact, that both, nitrogen uptake and nitrogen use efficiency (NUE) are largely influenced by water avaibilty, the efficiency of nitrogen utilization is considered together with the water use efficiency. The purpose of the study was to characterize the productivity of maize for grain, as well as water and nitrogen use efficiency of the crop in long-term field experiment.

Materiał and Methods

Field experiments were carried out at two experimental stations of the Institute of Soil Science and Plant Cultivation in Poland, in Grabów and Baborówko, between 2003-2013. Maize was grown in the rotation of winter oilseed rape-winter wheat-maize-spring barley, and was fertilized with ammonium nitrate: 50, 100, 150, 200 and 250 kg N·ha^{-1}. In the period of the investigations, the average annual rainfall in Baborówko at the vegetation of maize was 320 and in Grabow 371 mm. According to the methodology proposed by EU Nitrogen Expert Panel (EU NEP), the following indices were calculated: grain yield (Yd), nitrogen use efficiency (NUE), nitrogen uptake (Nup), nitrogen surplus (Ns), water use efficiency (WUE), nitrogen utilization efficiency (NutEY).

Results and Discussion

The yields of maize oscillated within 1.22-15.8 t·ha^{-1}, with the mean of 7.59 t·ha^{-1} (Table 1). Statistically significant increase was proven up to 150 kg N·ha^{-1}, which provided the grain yield of 8.03 t·ha^{-1}. The increase of nitrogen uptake was statistically significant up to the dose of 200 kg N·ha^{-1}, which corresponded with nitrogen uptake equal to 196 kg N·ha^{-1}. NUE dropped systematically with N doses and at 250 kg N·ha^{-1} reached the value 80%. It was the only value which fell within the desired range of 50-90%, resulting in the acceptable nitrogen surplus Ns = 51 kg N·ha^{-1} (Ns < 80 kg N·ha^{-1}). WUE grew statistically significant to the rate of 150 kg N·ha^{-1}, when reached the value of 14.5 kg·mm^{-1}. Further increasing of nitrogen doses resulted in negligible growth of the parameter. It suggests that water use efficiency for maize might be limited by a shortage of water in the range of 200-250 kg N·ha^{-1}. A trade-off relationship was found between NUE and WUE in the experiments – NUE decreases, while WUE grows with increasing nitrogen rates (Fig.1). The relationship allowed to state, that in the desirable range of NUE 50-90% (EU Nitrogen Expert Panel, 2015), WUE values will be within in the narrow range of 14,9-15,7 kg·ha^{-1}mm^{-1} (Fig.1).

Table 1. The mean values of yield, nitrogen uptake, nitrogen use efficiency, nitrogen surplus, water use efficiency and nitrogen surplus in the experiments

Year	Yd	Yn	NUE	Ns	WUE	NutEY
	t ha^{-1}	kg ha^{-1}	%	kg ha^{-1}	kg ha^{-1} mm^{-1}	kg kg^{-1}
2006	1,84	105	85	45	3,6	22,6
2003	4,51	128	107	22	7,9	33,5
2005	6,89	157	129	-7	12,3	45,5
2004	7,28	159	135	-9	13,4	46,0
2010	7,46	192	159	-42	13,4	39,5
2013	7,53	172	134	-22	13,5	44,2
2008	7,54	159	128	-9	13,6	48,9
2007	8,76	201	160	-51	15,5	44,6
2012	8,81	188	147	-38	15,8	47,9
2009	11,24	192	148	-42	20,4	59,6
2011	11,61	227	184	-77	21,0	51,9
HSD$_{0.05}$	0,824	20,4	20,2	20,4	1,47	4,07

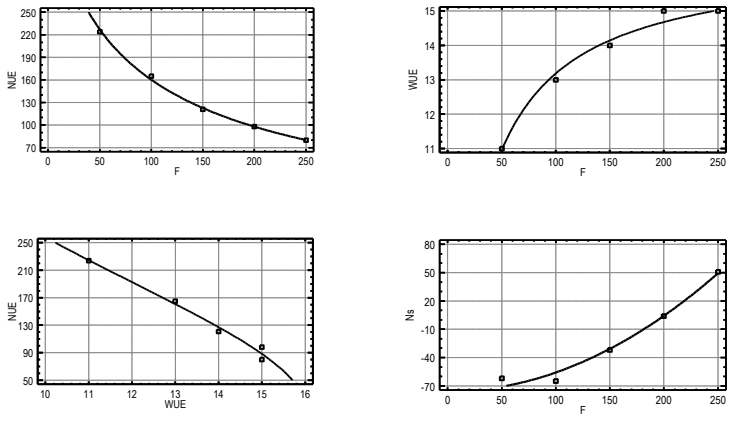

Figure 1. The relationships between NUE (%) and N rate (F, kg N·ha^{-1}), WUE (%) and N rate, NUE and WUE, N surplus (Ns, kg ha^{-1}) and F

Conclusions

The results of long-term field experiments with maize grown in Eastern and Western Poland showed that the rate of 150 kg N·ha^{-1} is optimal for the productive and environmental purposes. Such rate secured grain yield of 8.03 t·ha^{-1} nitrogen uptake of 182 kg N·ha^{-1}, NUE 128%, WUE 14.5 kg·ha^{-1}·mm^{-1}, efficiency of nitrogen utilization 43 kg·ha^{-1} and N surplus minus 32 kg N·ha^{-1}. These values are close to the recommended by EU NEP.