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Nitrogen use efficiency of winter wheat on farms in Poland

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Abstract. Improving Nitrogen Use Efficiency (NUE) in cereal cultivation is of high importance for providing nutrition for the growing population in the world while at the same time reducing the overburdening of the environment with the non-productive excess of reactive nitrogen. Wheat is one of the most vital cereals in human and animal nutrition worldwide. In this study, NUE, N yields (Yn) and N surplus (Nb) of wheat were estimated on the basis of a random survey of 1182 winter wheat growing farms in Poland. The purpose was to characterize the practices of N fertilization on the tested farms, and to identify potential possibilities for improving NUE in winter wheat production in Poland. The assessment of NUE, Yn and Nb was based on the methodology tentatively proposed by the EU Nitrogen Expert Panel (EU NEP). In the entire population of farms, the median and median absolute deviation of the tested characteristics were as follows: N dose 114 ± 30 kg N/ha, NUE 89 ± 18%, Yn 100 ± 15 kg N/ha, and Nb 12 ± 23 kg N/ha. The estimated range of NUE (71–107%) indicated that in a part of the farms, NUE was larger than 100%, which means the risk of N soil mining. Such high values were recorded in approximately 50% of the farms, and may undermine the long-term sustainability of wheat production. If NUE in these farms was to achieve the desirable values of 70–90%, the N doses applied would have to increase from 104±19 to 134±20 kg N/ha. It would result in an increase of grain yield from 4.80 ± 0.8 to 6.00 ± 0.8 t/ha and of N yield from 91 ± 15 to 113 ± 16 kg N/ha.

Keywords: winter wheat, Nitrogen Use Efficiency (NUE), farm fields

INTRODUCTION

In recent years, there has been an increased interest in activities that would lead to improving Nitrogen Use Efficiency (NUE) in the entire agricultural production (EU-NEP, 2015; Oenema, 2015; Norton et al., 2015; Brentrup, Palliere, 2010). These activities are motivated by, on the one hand, the need to increase agricultural production for meeting nutritional requirements of the growing world's population (Ray et al., 2013), and on the other hand, the need to reduce the losses of reactive nitrogen (Nr) (Erisman et al., 2013; Galloway et al., 2008). The improvement of NUE, which is to be achieved in the entire chain of food production, requires, in the first place, the improvement of NUE in farms, as they constitute the first link of the chain of production (EU NEP, 2014; EU NEP, 2015; Billen et al., 2014; Oenema, 2015).

NUE in cereal production has long attracted interest due to the importance of cereals in the diet of humans and animals, and also because of their large share of the land use area. The agronomic, physiological, and genetic methods for NUE improvement in cereal crops are fairly well recognized (Barraclough et al., 2010; Hawkesford, 2014; Hirel et al., 2011; Rasmussen et al., 2015; Zhang et al., 2015a; Zhang et al., 2015b). Despite this, NUE in these crops is generally low, amounting to 42% on a global scale (Zhang et al., 2015b). In Poland, the NUE for basic cereals, estimated on the basis of data from public statistics, oscillate between 50–71% (Faber et al., 2016). Due to the large proportion of winter wheat in Poland's total cropland (13.7%), the possibility of improving NUE should be carefully considered.

This paper presents the estimates of NUE, N yield (Yn), and N surplus (Nb), calculated on the basis of a random survey of 1182 farms growing winter wheat (grain yields, N dose). The listed estimates were used to characterize N fertilization practices and to identify potential possibilities for improving NUE in winter wheat in Poland.

MATERIALS AND METHODS

Farm data were collected randomly from farms growing winter wheat in rotation with other crops in the years 2008–2013 in Poland through a survey. The collected data

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included grain yield (Yd, t/ha, moisture 15%) and the N doses (N) in mineral fertilizers (kg N/ha). The applied N doses were increased only by the N from atmospheric deposition, which amounted to 14 kg N/ha, because animal manures and green manures were not used. The efficiency of N fertilization was estimated on the basis of grain yields and N input (F, kg N/ha)

NUE (%) was assessed on the basis of the following formula, proposed by EU NEP (2014):

NUE = (Yn/F) * 100 [1]

where: Yn (kg N/ha) – nitrogen yield (= N uptake by grains = N output), F (kg N/ha) = N dose + N from deposition (N input).

Nitrogen yield Yn (kg N/ha) was assessed according to the formula (Brentrup and Palliere, 2010):

Yn = yield of the major product * mean N concentration [2]

The average N concentration in winter wheat grains was taken from the ISSPC database = 1.89% dm.

N balance (Nb; = N surplus, kg N/ha) was assessed according to (EU NEP, 2014):

Nb = F – Yn [3]

Nb is related to NUE and Yn according to:

Nb = Yn * (1/NUE – 1) [4]

Nb is usually interpreted as a partial N balance.

The variability of F, Yn, NUE, and Nb in the entire set of farms was characterized with medians (Me), median absolute deviation (MAD), and minimum and maximum values.

The assessment of the impact of fertilization practices applied in the farms on the value of NUE was carried out using two methods. The first one was related to the early studies of EU NEP (2014), which assumed that the tentative values of NUE (%): <70 indicate excessive N fertilization, causing environmental pollution, 70–90 correspond to the desired N fertilization, while > 90 mean a too small N fertilization, causing the overexploitation of N resources from the soil. By adopting this categorization, in which NUE is the main criterion for the assessment of fertilization, the regression between NUE and F ($NUE=(a+b/F)^{\wedge 0.5}$) was estimated and the range of F values ensuring the desired NUE 70–90% was determined. According to this range, the entire set of data for the farms was divided into three subsets depending on their F values: too low, sufficient, and too high to achieve the desired NUE of 70–90%. In these subsets, the variability of F, Yn, NUE, and Nb was characterized in the previously described manner. The second method used for assessing the impact of fertilization practices on NUE was compliant with the currently adopted descriptive determination of the desirable range for NUE, Yn and Nb (Oenema, 2015; EUNEP, 2015). The possible targets assumed in the method were: NUE 50–90%, the desired maximum N surplus (Nb) < 80 kg/ha/yr and the desired minimum productivity Yn > 80 kg/ha/yr. The evaluation of fertilization practices in all the farms was presented as a graphical presentation, as well as numerical data for the four subsets of farms (F1–F4):

– NUE > 90% (risk of soil mining) (F1),
– NUE 50–90%, Yn < 80 kg N/ha/yr (risk of Yn limitation) (F2),
– NUE 50–90%, Yn > 80 kg N/ha/yr, Nb < 80 kg N/ha/yr (desirable range for NUE, Yn and Nb) (F3),
– NUE < 50% (risk of inefficient N use) (F4).

The variability of F, Yn, NUE, and Nb in these subsets of farms was characterized in the previously described manner.

RESULTS

The tested variables were characterized by skewed statistical distributions, as their values and variability were characterized by medians, MAD and the minimum and maximum values. The yields in the tested farms oscillated within 1.5–11.0 t/ha with the median of 5.5 t/ha and MAD of 0.8 t/ha (5.5±0.8 t/ha) (Table 1). They were obtained at N doses ranging between 30–234 kg N/ha (114±30 kg N/ha). The values of Yn, NUE, and Nb, assessed for the listed variables, were calculated to be within fairly wide ranges (Table 1). NUE oscillated between 24–212% (89±18 %).

There was a fairly close dependency between NUE and F, described with the regression equation of $NUE = (-1877.65 + 1.19475E6/F)^{\wedge 0.5}$ (Fig. 1). From this dependency, it was assessed that in order to achie-

Table 1. Grain yield (Yd), nitrogen yields (Yn), nitrogen doses (F), nitrogen use efficiency (NUE) and nitrogen balance (Nb) (n=1182)

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	5.30	114	100	89	12
MAD	0.80	30	15	18	23
Minimum	1.50	30	28	24	-76
Maximum	11.0	234	208	212	130

n – number of farms

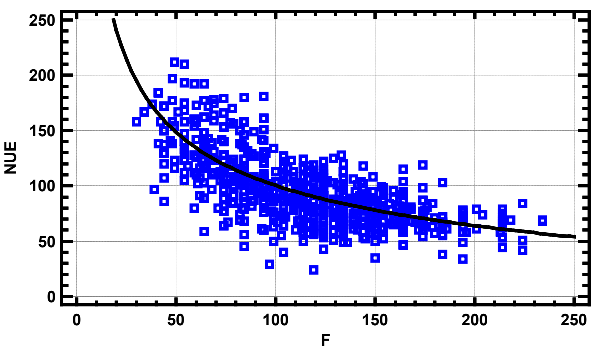

Fig. 1. The relationship between NUE (%) and N dose (F, kg N/ha) for 1182 farms in Poland (r^2=55.4%) in 2008–2013

ve NUE of 70–90%, fertilization with 120–175 kg N/ha would have to be applied in the farms tested. Adopting this range, the entire set of data was divided into three subsets of farms, in which fertilization (kg N/ha) was: too low (<120), sufficient (120–175) and too high (>175).

The group of farms applying less than 120 kg N/ha constituted 56% of their total number (Table 2). These farms were obtaining grain yields of 4.8 ± 0.8 t/ha at a median fertilization of 92 ± 18 kg N/ha. Nitrogen yields (91 ± 15 kg/ha) and NUE (104 ± 20%) resulted in overall negative values for Nb. On the basis of the data presented, nitrogen economy in these farms could be classified as extensive.

Table 2. The yields of grains (Yd), nitrogen yields (Yn), nitrogen dose (F), nitrogen use efficiency (NUE) and nitrogen balance (Nb) on 664 farms growing winter wheat in Poland with less than 120 kg N/ha/year

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	4.80	92	91	104	-3
MAD	0.80	18	15	20	16
Minimum	1.50	30	28	24	-76
Maximum	9.00	119	170	212	91

Farms with the N fertilization level of 120–175 kg N/ha (139 ± 11) accounted for 39% of the total farm number. They had higher grain yield (6.0 ± 0.8 t/ha) and nitrogen yield (113 ± 16 kg/ha) than the first group (Table 3). NUE in these farms fell within the desired range (78±9%), while Nb was still modest (30±14 kg/ha). The presented characteristics suggest that nitrogen fertilization in these farms was rational.

Table 3. Grain yields (Yd), nitrogen yields (Yn), nitrogen dose (F), nitrogen use efficiency (NUE) and nitrogen balance (Nb) on 456 farms growing winter wheat in Poland using nitrogen fertilization rates of 120-175 kg N/ha/year

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	6.00	139	113	78	30
MAD	0.80	11	16	9	14
Minimum	2.80	120	53	35	-37
Maximum	11.00	175	208	128	97

The third group of farms (5% of the total) applied the highest level N fertilization (194 ± 10 kg N/ha), and had the highest grain yield (6.8 ± 0.8 t/ha), nitrogen yield (128 ± 15 kg N/ha) and Nb = 66 ± 14 kg N/ha (Table 4). At the same time NUE was lower (67 ± 6%) than in the second group (Table 3).

Table 4. Grain yields (Yd), nitrogen yields (Yn), nitrogen dose (F), nitrogen use efficiency (NUE) and nitrogen balance (Nb) on 62 farms growing winter wheat in Poland with N fertilization levels higher than 175 kg N/ha/year.

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	6.75	194	128	67	66
MAD	0.75	10	15	6	14
Minimum	3.50	176	66	34	-5
Maximum	10.00	240	189	103	130

An evaluation of fertilizer practices in the surveyed farms with the currently adopted NUE ranges (Oenema, 2015, EU NEP, 2015), N output (Yn) and N surplus (Nb) is presented graphically (Fig. 2)

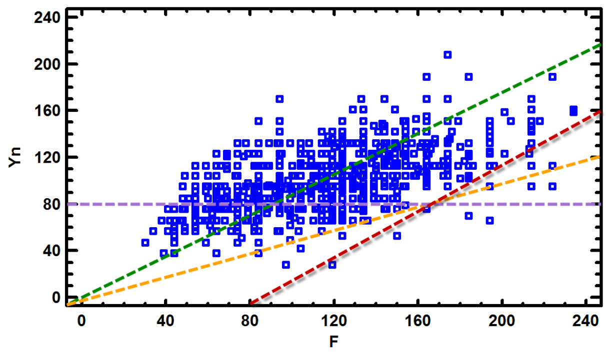

Fig. 2. Desirable range for NUE (%), N output (Yn, kg N/ha/yr) and N surplus (Nb, kg N/ha/yr) depending on N input (F, kg N/ha/yr) for 1182 winter wheat farm fields.

Farms (F1) located on the left of the green line (49% of the total) have an excessively high NUE (>90%), which brings the risk of soil mining. Farms (F3) located in the area designated by purple, green, and red lines (38% of the total) also have the desirable range of NUE, Yn and Nb. Farms (F2) located in the triangle between the purple, green, and yellow lines (11% of the total) show NUE in the desirable range (50–90%), but their nitrogen yield is too low (<80 kg N/ha/yr). Farms (F4) located to the right of the yellow line (2% of the total) have a too low NUE (<50%), which brings the risk of inefficient N use. Numerical values of the tested variables in the four groups of farms are presented in tables 5-8. Farms F1 operate with a negative N balance, resulting from a low N fertilization (89 ±25 kg N/ha) (Table 5). However, their medians of grain yields (5,5±1,0 t/ha) and nitrogen yields (104±19 kg N/ha) are relatively high, despite being obtained under the risk of soil mining.

Table 5. Grain yields (Yd), nitrogen yields (Yn), nitrogen dose (F), nitrogen use efficiency (NUE), and nitrogen balance (Nb) – on 575 farms growing winter wheat in Poland under risk of soil mining (F1)

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	5.50	89	104	113	-11
MAD	1.00	25	19	15	12
Minimum	2.00	30	38	91	-76
Maximum	11.00	184	208	212	13

Table 6. Grain yields (Yd), nitrogen yields (Yn), nitrogen dose (F), nitrogen use efficiency (NUE), and nitrogen balance (Nb) - on 19 farms growing winter wheat in Poland under risk of inefficient N use (F4)

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	3.50	136	66	45	74
MAD	0.70	28	13	5	17
Minimum	1.50	84	28	24	46
Maximum	5.00	224	95	50	130

Table 7. Grain yields (Yd), nitrogen yields (Yn), nitrogen dose (F), nitrogen use efficiency (NUE) and nitrogen balance (Nb), on 134 farms growing winter wheat in Poland under risk of N yield limitation (F2)

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	3.90	100	74	69	28
MAD	0.20	16	4	11	12
Minimum	2.00	44	38	51	6
Maximum	4.00	154	79	90	75

Increasing N fertilization did not result in an increase in yields in F2, F3, and F4 farms, as compared to the F1.

It may suggest that their response to N fertilization was limited by factors other than N. The biggest limitations occurred in F4 (Table 6) and F2 farms (Table 7), where, grain yields decreased despite increasing N doses.

In F3 farms (Table 8), which obtained desirable NUE, Yd and Nb at the N dose of 144±18 kg N/ha, the yields of grains and nitrogen were the same as in F1 farms, which indicates that they were limited by the activity of factors other than nitrogen.

Table 8. Grain yields (Yd), nitrogen yields (Yn), nitrogen dose (F), nitrogen use efficiency (NUE) and nitrogen balance (Nb) – on 441 farms growing winter wheat in Poland with desirable NUE, N yield, and N surplus (F3)

Statistics	Yd t/ha	F kg/ha	Yn kg/ha	NUE %	Nb kg/ha
Median	5.50	144	104	76	32
MAD	0.50	18	9	7	11
Minimum	4.30	94	81	57	9
Maximum	10.00	234	189	90	78

DISCUSSION

The median NUE for wheat in Poland, assessed on the basis of public statistics (1999–2014) amounted to 65% (Faber et al., 2016). The median N dose was 118 kg N/ha, N yield – 80 kg N/ha, and N surplus – 40 kg N/ha. These values fall within the desired range for NUE (50–90%) according the EU NEP (Oenema, 2015; EUNEP, 2015). The results for wheat-growing farms presented in this work roughly support the conclusions of the study by Faber et al. (2016). On 1182 farms, the medians of the tested characteristics oscillated as follows: N dose 114 ± 30 kg N/ha, NUE 89 ± 18%, N yield 100 ± 15 kg N/ha, and N surplus 12 ± 23 kg N ha. In these farms, the efficiency of fertilization was generally better than the efficiency determined on the basis of public statistics for the entire country (Faber et al., 2016). The analyses showed that a significant number of farms – 33% were in the NUE range of 70–90%, and for 39% of the farms the desired NUE ranged between 50–90%. This means that in these farms changes in the nitrogen fertilization will not be necessary. On the other hand, 49% farms had NUE higher than 90%, which indicates the risk of N soil mining. In these farms N doses were low 89 ± 25 kg N/ha, respectively. This indicates that the improvement of NUE in the these farms should be attributed to increasing N doses. The regression of NUE vs F showed that the increase of N dose (139 ± 11 kg N/ha) theoretically lowered NUE to the value close to the desired one (78 ± 9%), and increased nitrogen yield (113 ±16 kg N/ha). When, however, the efficiency of fertilization was characterized using NUE, N yields and N surplus jointly, it was found that the increase of N dose (144 ± 18 kg N/ha) brought NUE to its desirable values (76 ± 7%), but it did not lead to an increase in grain and nitrogen yields (Table 5 and 8). These findings may suggest that yields of grain and N were limited in farms by factors other than nitrogen.

CONCLUSIONS

In almost half of the surveyed farms winter wheat was extensively fertilized with nitrogen, which in turn caused their NUE to be higher than 90%. In consequence, in these farms there was a risk of soil N mining. In this situation, it would be advisable to increase N doses for the improvement of the NUE. However, as it was demonstrated, obtaining the desired NUE may not lead to an increase in yields, which suggests it may be limited by factors other than nitrogen. Thus, until the yield-restricting factors have been removed, obtaining the desired NUE may not arouse interest of wheat producers.

REFERENCES

Barraclough P.B., Howarth J.R., Jones J., Lopez-Bellido R., Parmar S., Shepherd C.E., Hawkesford M.J., 2010. Nitrogen efficiency of wheat: Genotypic and environmental variation and prospects for improvement. European Journal of Agronomy, 33: 1-11.

Brentrup F., Palliere C., 2010. Nitrogen use efficiency as an agro-environmental indicator. OECD workshop "Agri-environmental indicators: lessons learned and future directions", 23-26 March, Leysin, Switzerland.

Billen G., Lassaletta L., Garnier J., 2014. Some conceptual and methodological aspects of NUE of agro-food systems. The note at the attention of the EU N-expert panel. Windsor, Sept 15-16, 2014 (manuscript).

Erisman J.W., Galloway J.N., Seitzinger S., Bleeker A., Dise N.B., Petrescu A.M.R., Leach A.M., de Vries W., 2013. Consequences of human modification of global nitrogen cycle. Philosophical Transactions of the Royal Society B 368, 20130116.

EU Nitrogen Expert Panel – Fertilizers Europe (EU NEP), 2014. Nitrogen Use Efficiency (NUE) – an indicator for the utilization of nitrogen in food systems. Draft proposal – version 4 September, 2014, Windsor, UK, 15-16 September 2014; organized by Fertilizers Europe (manuscript).

EU Nitrogen Expert Panel, 2015. Nitrogen Use Efficiency (NUE) an indicator for the utilization of nitrogen in food systems. Wageningen University, Alterra, Wageningen, Netherlands.

Faber A., Jarosz Z., Kopiński J., Matyka M., 2016. The relationships between nitrogen use efficiency and nitrogen input in crop production in Poland. Polish Journal of Agronomy, 26: 15-20.

Galloway J.N., Townsend A.R., Erisman J.W. et al., 2008. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science, 320: 889-892.

Hawkesford M.J., 2014. Reducing the reliance on nitrogen fertilizer for wheat production. Journal of Cereal Science, 59(3): 276-283.

Hirel B., Tètu T., Lea P.J., Dubois F., 2011. Improving Nitrogen Use Efficiency in crops for sustainable agriculture. Sustainability, 3: 1452-1485.

Norton R., Davidson E., Roberts T., 2015. Position Paper: Nitrogen Use Efficiency and Nutrient Performance Indicators. Global Partnership on Nutrient Management. Tech. Paper 01/2015 (http://www.unep.org/gpa/documents/publications/NUEandNPIGPNM2015.pdf).

Oenema O., 2015. The EU Nitrogen Expert Panel and its indicator for Nitrogen Use Efficiency (NUE). EXPO Milano, Milano 10.09.2015 (http://fertilizerseurope.com/fileadmin/documents/1.%20COMMITTEES/COMMUNICATION/EXPO_Milano/EU-NEP-Oenema-EXPO_MILANO_03-09-2015.pdf).

Rasmussen I.S., Dresbøll D.B., Thorup-Kristensen K., 2015. Winter wheat cultivars and nitrogen (N) fertilization – Effects on root growth, N uptake efficiency and N use efficiency. European Journal of Agronomy, 68: 38-49.

Ray D.K., Mueller N.D., West P.C., Foley J.A., 2013. Yield trends are insufficient to double global crop production by 2050. PLoS One 8, E66428.

Zhang X., Mauzerall D. L., Davidson E. A., Kanter D. R., Cai R., 2015a. The economic and environmental consequences of implementing nitrogen-efficient technologies and management practices in agriculture. Journal of Environmental Quality, 44: 312-324.

Zhang X., et al., 2015 b. Managing nitrogen for sustainable development. Nature, 528, 3 December 2015, 51-59.

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