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## NITROGEN SURPLUSES IN THE WYSKOĆ DITCH CATCHMENT (POLAND) IN RELATION TO SPATIAL FIELD STRUCTURE AND INTENSITY OF AGRICULTURAL ACTIVITY

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### ABSTRACT

The balances of nitrogen (N) at the field level are currently used as an important basis for monitoring the N losses to surface and groundwater in Europe. Dominant role in the characteristics of N excesses and their variability have a recognition of functional, direct relationships between the inflows and outflows of this component to and from the fields. To date, little data exist on the mutual relationship concerning the importance of the spatial structure of fields, their degree of fragmentation and intensity of production in the catchment area with regard to variability of N surpluses. The aims of this paper were to estimate N surpluses at field levels across the whole catchment area and to explore the possible relations between N surpluses and spatial characteristics of agricultural fields as well as intensity level of agricultural production. The study was conducted in the Wysock Ditch catchment (Wielkopolska Region, Poland) in the years 2008–2009. The study area, featuring a diversified landscape and strongly shaped by agricultural activities, included a total of 101 farms with 1152 fields. The results showed a wide variation of fields fragmentation (irregularities of shapes) and sizes of fields. In terms of the spatial diversity the agricultural area was classified into two clusters through the use of a multivariate statistical method – cluster analysis. There was a significant difference in N surplus between the separated clusters of fields. The mean N balance in the cluster of fields with small size and irregular shape was  $31.2 \text{ kg ha}^{-1}$  against a higher N balance of  $57.1 \text{ kg ha}^{-1}$  in the other cluster consisting of larger fields with simpler regular shapes. Large differences in N surpluses were explainable by higher supply of mineral N to fields in the second cluster. The nature of relationships between variables indicated that increased N surpluses were closely associated with a larger share of forages and root crops in the cropping area, as well as with stocking density. It was concluded that achieving higher productivity on large size fields with cereals and oil plants prevented excesses of N in those fields.

**Key words:** agricultural catchment, spatial structure of fields, nitrogen surplus, mineral nitrogen fertilization, intensity of plant production.

### INTRODUCTION

In the catchments of West Polish lowland, agriculture is the main source of anthropogenic nitrogen (N) [Jankowiak et al. 2003]. Regular excess of inflowing N over its requirements by cultivated plants creates a balance surplus at the fields surface, thus contributing to an increased risk of N leaching from arable soils both to the groundwater and surface waters. Given the necessity of prevention of non-point source pollution and the spread of N compounds in the environment, the useful tools for monitoring these types of risks are indicators of balance surpluses at the field level, mineral N fertilization and N use efficiency in crop production [Banasik et al. 1998, 1999, Fotyma et al. 2000, Simon et al. 2000, Swensson 2003, Biełkowski 2011]. In programs promoting environmental protection and in those implemented under the EU Common Agricultural Policy, the N balance is considered the main tool for assessing the environmental impact of agricultural production systems and land use [Communication from the Commission to the Council and the European Parliament 2006]. The OECD also considers N balance an important instrument for determining the threat of N pollution from agricultural areas [Environmental Indicators for Agriculture 1999]. It is presently accepted that the potential for N leaching from fields can be in an appropriate manner determined by the N excess related to the field surface. The balance at the farm gate is, in turn, more useful for monitoring the efficiency of N use in scale of the whole farm, and in assessing capability of farms to reduce emissions of N compounds into the atmosphere [Watson

and Atkinson 1999].

Calculation of N excesses in agricultural systems, by the balance-sheet method, allows one to investigate in a system-analytical way all sources of N inputs and its uptake by plants. The area scales for calculations range from N balances per individual fields, and all fields within the farm, to N balance for the whole region, country and the world [Sheldrick et al. 2002, Van Beek et al. 2003]. To date, detailed studies on N balances were performed for a dispersed groups of farms. However, there are few detailed studies showing the spatial distribution of N surpluses in an entire area located within the natural boundaries of the catchment. Due to a requirement for the collection of large amounts of data and the accompanying workload it is difficult to reach a sufficient degree of detail for the general N balance in the agricultural catchment when this is not obtained by aggregation from the individual field balances. Therefore, the N balance results are rarely presented for the whole basin in a spatial layout.

A single catchment area is usually not uniform in terms of agricultural activities, which are carried out by the various types of farms with different production technologies. Another spatial feature of catchments can be the presence of diverse landscape forms and soil conditions that determine the zone boundaries for different forms of land uses and crop field shapes, which may influence the environmental effects of agricultural production by creating various types of biogeochemical barriers limiting the discharge of N compounds to waters [Ryszkowski and Kędziora 1995]. The mutual interaction in the spatially varying conditions of a catchment between natural environment, economic factors and technological developments over a longer time span affects the size and shape of fields in agricultural areas. These changes in the structure of a landscape can modify the quantity of water runoff to rivers and leaching of nitrates. Among the factors that influence N losses from the catchment are mentioned: structure of land use, presence of buffer zones, spatial allocation of N point sources, fertilizer rate and its effectiveness, stocking density, as well as topography of the terrain and soil quality [O'Neill et al. 1988, Cellier et al. 2011].

The averaged N balances at the field level of farms take up a role of regulatory instruments in environmental policy [Code of Good Agricultural Practice 2004]. At the same time many studies show a great variability in amount of surpluses over larger areas [Zbierska et al. 2002]. Without knowing the distribution of N balance excesses the ability to accurately identify sites with a potential for increased N leaching to surface waters and groundwater can be significantly impaired. Consequently, it is also hard to take protective action programs in a more synchronized way by farms whose fields have an increased risk of N losses to the environment.

The aim of the study was to develop the spatial distribution of N balances in the Wyskoć agricultural catchment by including multiple sources of N inflow and its outflow for all fields in this area. Because of the existing asymmetry in the shape and size of fields, this catchment was useful to assess the relationship between N surpluses on the fields and the production intensity, and the degree of fragmentation of the agricultural landscape.

## MATERIALS AND METHOD

The study area was located in the Wyskoć micro-catchment with a size of approximately 22.5 km<sup>2</sup>, situated in the southeast part of Kościan plain (Wielkopolska Region). The catchment represented the Polish study landscape for the EU NitroEurope research program (2006–2011). The terrain configuration is mostly flat with an average height of 80 m above sea level. The landscape of the catchment is dominated by agricultural land use (arable land constitutes over 89% of the area). A characteristic element of the landscape is woodlots with a total length of 45 km. The soils in the catchment area are of medium agricultural suitability. They are of ground moraine origin developed from boulder clay. With regard to the granulometric composition of arable soils, the fractions of light loamy sands (73%) and very light loamy sands (18.2%) predominate. Catchment area is characterized by the substantial degree of variability of fields fragmentation, the irregular shapes and sizes of the fields.

The investigation involved all farms whose crop fields were located within the catchment. In the area there are multiple sources of N emission present with scattered places of livestock buildings and manure storage. The distribution of farms is diverse showing complex farming activities. The study used real data from 101 farms based on survey data and questionnaires. Fifty percent of the analyzed objects had land acreage within the range 7.6–17.0 ha. Their share in total agricultural area accounted for approximately 15%. Almost 68% of the total land was concentrated in three large legal entities, well over 300 ha. The farms studied exhibited complex farming activities. Among them six types of agricultural production were distinguished: dairy, pig production, field crops production, fruit growing, horse breeding and mixed livestock production. Almost 71% of farms had the mixed type of animal production. On average, over 39% of total agricultural land of surveyed farms were placed inside the catchment. The largest share of agricultural land in the catchment had dairy farms (51.3%), mixed livestock farms (35.3%) and horse breeding farms (9.3%).

The results of the survey, undertaken in 2008 and 2009, was the construction of Access® and GIS farm databases which were a principal source of data for the presented study. The registry database included detailed description of 1522 fields, with the area equal to 45.6 km<sup>2</sup>. Each plot of land was mapped and allocated to one of 101 farms. The catchment area included 698 fields. The data recorded consisted of the following categories: a) characterization of livestock buildings (bedding and flooring types, feed type and feed amount, numbers and types of animals); b) description of agricultural practices and production results in fields (sowing dates, the types of mineral fertilizer applied to a field, crop yield, cultivation operation, crop residue management); c) description of manure storage conditions and disposal of manure to fields; d) grazing periods and number of animal grazed, annual balance of main materials and agricultural produce on farm. The developed system for the identification of fields allowed for their spatial locations. Linking GIS data on land use and field data created an opportunity to examine the spatial distribution of the N balance surpluses.

Due to the large heterogeneity of the field shapes which is a regular feature of the catchment landscape, crop fields were divided into two distinct groups. Spatial allocation of fields to one of the groups was based on variables of the field size and the field shape ratio. Two subsets of fields with similar elements were distinguished by cluster analysis. Calculations were performed using K-means procedure which assigns each point to the cluster whose center is nearest [Sharma 1995].

The formation of fields in the catchment was characterized by the field shape indicator that takes into account field perimeter and its surface. This indicator is calculated as:

$$WKRP = \frac{D}{S} \quad (1)$$

where:  $WKRP$  – the field shape indicator ( $\text{m ha}^{-1}$ ),  $D$  – the perimeter of field (m),  $S$  – the field area (ha).

The degree of fragmentation of the farm area was determined using a modified Simpson's Index (O'Neill et al. 1988). The method for calculating this index is presented by the following formula:

$$WS = 1 - \frac{\sum_{i=1}^n a_i^2}{(\sum_{i=1}^n a_i)^2} \quad (2)$$

where:  $WS$  – Simpson's Index,  $a$  – area of the field  $i$ ,  $i$  – individual fields of farm ( $1, \dots, n$ ).

Simpson's index ranges from 0 to 1. It is equal to 0 when the farm has only one field. An index value close to 1 indicates a highly fragmented farm, i.e. having a large number of fields of similar area. Simpson's Index, unlike the previous indicator, does not consider the shape of fields and thereby characterizes less well the diversity of the agricultural landscape, as well as operational conditions on the fields.

The N surplus was calculated for all fields in the catchment. It is the difference between the amount of N flowing into the field from various external sources and its uptake by plants. The calculation method, in  $\text{kg N ha}^{-1}$  of agricultural land, is given below [Biełkowski and Jankowiak 2006]:

$$\begin{aligned} N_{\text{surplus}} = & N_{\text{mineral fertiliser (after taking into account the gaseous losses of N}_2\text{O and NH}_3)} + \\ & N_{\text{deposition from the atmosphere}} + N_{\text{biological fixation}} + N_{\text{ploughed plant residues}} + \\ & N_{\text{manure and slurry (after gaseous losses of N}_2\text{O and NH}_3)} - N_{\text{harvested}} \end{aligned} \quad (3)$$

This accounting approach for quantifying nutrient surpluses was proposed by Granstedt [2000]. In Poland, model of N field balance calculation, integrated into decision support system for nutrient management (named "MACROBIL"), also uses similar inputs and outputs entries [Fotyma and Jadczyński 2001]. Estimates of N losses as ammonia ( $\text{NH}_3$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ) from manure were made separately for each livestock category in the studied farms, taking into account annual livestock populations, average N excretion per head and different types of manure management systems. N emission in the forms of  $\text{NH}_3$  and  $\text{N}_2\text{O}$  from manure was calculated based on the accepted emission factors, considering different types and forms of manure collection and methods of application on farm fields [EMEP/CORINAIR Emission Inventory Guidebook 2002]. Information on concentration of N in the main crop and plant residues was obtained from literature data [Kerschberger et al. 1997]. For the calculation of emissions of N compounds from fertilizers, emission factors for different fertilizers were used, which were determined for the third group of countries with moderate and cooler climate and acidic soils [EMEP/CORINAIR Emission Inventory Guidebook 2002].

The Bi-plot method with principal component analysis was used to identify the relationship between N surpluses at the field level and spatial fields structure, and intensity of agricultural production in the catchment. In the Bi-plot graph the main components form the graph coordinates and variables are presented as vectors [Kroonenberg 1995].

## RESULTS AND DISCUSSION

The investigated area was generally divided into two parts, with division lines running in south-west and easterly directions. The model of the spatial division of the land area into two clusters is shown in Figure 1. Two groups of fields were strongly differentiated with regard to the analyzed parameters (Table 1). The first cluster contained fields which were on average many times smaller than the ones allocated to the second cluster. The first group was also characterized by more irregular field shapes. The average value of field shape indicator was 5-fold lower than in the second fields group. Fields arranged in the second group were characterized by a greater uniformity in the spatial shape. It was reflected by a relatively smaller width of interquartile ranges of statistical parameters, as compared with the first set of fields. Major and clear differences of statistical parameters between distinguished clusters excluded existence of spatial similarity of fields in those two groups.



Fig. 1. Clusters of fields in the Wyskoć Ditch catchment

Table 1. Values of the statistical parameters for the fields size and the shape indicator in the whole catchment as well as for the distinguished fields clusters

Statistical parameters	Whole catchment		Cluster I		Cluster II	
	Field size [ha]	Field shape indicator [m ha <sup>-1</sup> ]	Field size [ha]	Field shape indicator [m ha <sup>-1</sup> ]	Field size [ha]	Field shape indicator [m ha <sup>-1</sup> ]
Mean	3.01	771.93	1.12	831.12	22.38	164.34
Stand. dev.	6.68	598.87	1.33	592.63	8.60	174.09
Median	0.78	661.38	0.68	700.02	21.02	120.22
Quartile I	0.29	394.28	0.26	474.92	16.22	97.59
Quartile III	2.00	988.12	1.50	1026.63	25.83	147.27

Nitrogen surplus, calculated at field level, averaged 48.3 kg ha<sup>-1</sup> for the whole catchment (Table 2). The percentage share of N from fertilizers in the makeup of inflows to fields was the highest (67%). Marked differences in N balance values occurred between the analyzed field clusters. The mean N surplus in the EC countries for the 1990s amounted to 52 kg ha<sup>-1</sup> [Statistics in focus 2000]. Estimated N balances in our study are comparable with those reported for the EC. Fotyma et al. [2001] reported a high N field balance for the group of 36 large size farms (company holdings) from the Wielkopolska region that was equal to 81.0 kg ha<sup>-1</sup> with a range of variation within 47–156 kg ha<sup>-1</sup>. In the first, highly fragmented group composed of small fields, N surplus was more than 45% lower compared to group II (including larger fields and a more favorable fields shape). N outflows from fields between the two separated groups were similar to each other. The analyzed clusters exhibited visible differences in total amount of N imported into the fields. For fields in group II, incoming N load was 20% that in the group I. The observed discrepancy can be explained by a higher intensity of crop production in the former. Mineral N fertilization in that area was in fact over 60% higher than in fields with a high degree of fragmentation. The lower mineral N fertilization rate on the fields of group I was compensated to a some extent by the use of larger quantities of manure. Probably farms with attribute of an unfavorable fields shape were more often involved in animal production and with a higher stocking density they had substantially larger amounts of manure per area unit at their disposal. Less intensively managed plant production in group I can be directly implicated in influencing higher use efficiency of N flowing to the fields as compared to group II. The average N utilization at field level in this catchment (72%) should be regarded as quite high. Kohn et al. [1997] define N use in crop production as high when the efficiency ratio is above 75%. In research on the nutrient balances in small-scale family farms for Wielkopolska region the N use was shown to vary depending on the type of production, with the highest degree of utilization of this element for crop farms – 78% and lower values for dairy and pig farms – 71% and 70%, respectively [Bieńkowski 2011]. Analysis of N surpluses through the so-called field level approach can be a more appropriate measure of pollution potential estimate by this element in the catchment than applying the N balance approach at the farm gate related holding area alone [Van Beek et al. 2003]. Because of too low resolution scale of a single farm area the specific details of spatial fields variability of N surpluses and environmental effects, which are the result of different production processes, fields structures and habitat conditions, cannot be captured. Through a precise identification of places (individual fields) with excessively high N balances the changes in agricultural management of unique fields can be undertaken, as well as facilitating closer monitoring of N flow throughout the farm.

Table 2. N surplus (kg ha<sup>-1</sup>) at field level for the whole catchment and for the distinguished fields clusters

Balance elements	Whole catchment		Cluster I		Cluster II	
	mean*	stand. dev. **	mean*	stand. dev.**	mean*	stand. dev.**
Inflows to fields, of which:	174.0	91.9	153.4	103.5	184.6	83.7
mineral fertilizers	117.1	45.6	82.3	36.0	134.9	39.3

manure	22.1	49.7	38.8	59.9	13.5	41.1
ploughed-in residues	11.7	23.3	9.9	23.5	12.7	23.3
biologically fixed N	12.0	60.7	11.4	53.6	12.4	64.4
atmospheric N deposition	11.0	–	11.0	–	11.0	–
Outflows (uptake in yield):	125.7	57.7	122.2	51.0	127.4	61.0
N surplus	48.3	67.1	31.2	75.9	57.1	60.5

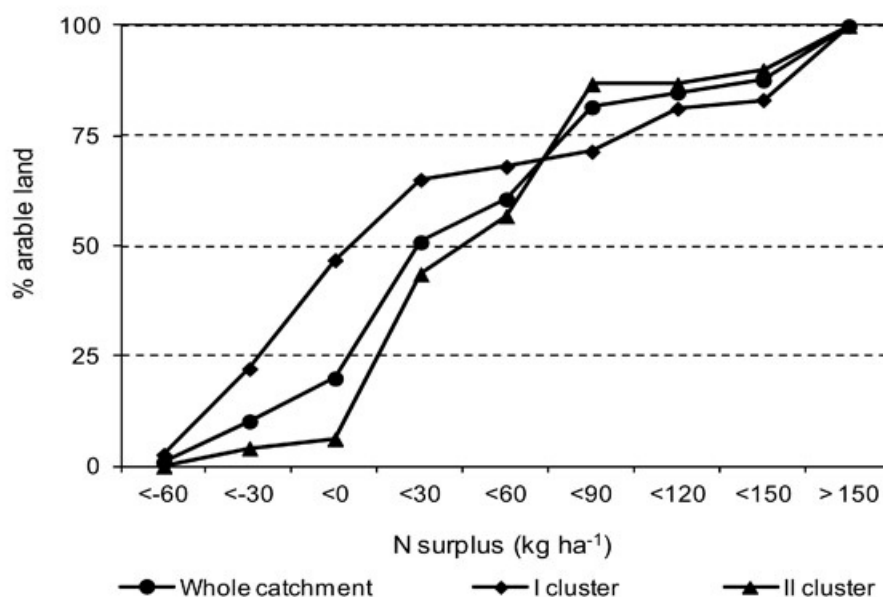


Fig. 2. Distribution of N surpluses for the whole catchment and for the distinguished clusters of fields, calculated in the accumulative way

The cumulative distribution of N surpluses at field level is shown in Figure 2. In both groups there were fields with negative N balances. Spatial differences of N surpluses occurred between compared clusters. In cluster II, cropped area percentage with N field balance lower than  $-30 \text{ kg N ha}^{-1}$  was negligible, in contrast to group I in which it was above 22%. For half of the area in that cluster, the N balance did not exceed  $4 \text{ kg ha}^{-1}$ , whereas it was below  $35 \text{ kg N ha}^{-1}$  in cluster II. Higher N surpluses, more than  $90 \text{ kg ha}^{-1}$ , were recorded for nearly 29% of total cropping area in cluster I and for only 13.2% of land in cluster II. This may indicate that despite the lower average N balance in group I, there are a number of fields in this area which due to high balances can be an important source of loss of this element into waterways by runoff or leaching. In studies on nitrate leaching in relation to N surplus, in the area of intensive dairy farming in British Columbia (Canada), it was found that the N excess above  $50 \text{ kg ha}^{-1}$  creates a risk of N leaching from the root zone [Zebarth et al. 1999]. Apart from much lower rainfall in the region of Wielkopolska, one can assume that the risk of N losses based on that threshold value would affect 34% and 45% of croplands in clusters I and II, respectively. For the Wielkopolska climatic conditions, the safe N surplus limit could be set at a higher level due to about half the rainfall than in British Columbia. In cluster I, relatively more fields are concentrated at the low and at the high ranges of N balances. Perhaps this may result from the diversification of management skills of farms with highly fragmented fields. The negative N balances can be in the long term unfavorable for achieving higher land productivity. In turn, high N excesses on a part of fields in this group may result from greater intensity of plant production. It can be assumed that this population of fields belongs to the market-oriented farms which decide on further intensification of existing land when they are not able to get production scale increases. Confirmation of internal differences in the management of N flows in fields integrated within cluster I can be high values of weighted standard deviations for N surplus and N inflow as compared to group II.

Broader basis for the explanation of balance differences between distinguished fields clusters can be different cropping structure, intensity of mineral fertilization and crop productivity. The most dominant plant group in cropping pattern of the whole catchment was cereals which accounted for 62% of sown area, followed by oilseeds (15.2%) and fodder plants (13.6%). Proportion of acreages in crop groups between both clusters turned out to be different (Figure 3). A share of area under cereals in the group I was 8.3% higher than in group II. In cropping pattern of cluster II, plants requiring higher N fertilization, i.e. oil plants and fodder plants prevailed. Differences in the distribution of land planted to those crops between two fields clusters were probably a reflection of different farming systems involving different crop preferences and crop rotation on fields assigned to the analyzed groups. A large share of cereals and a relatively high proportion of forages suggests that harvested crops in the group of small fields are probably associated more with their use as a forage base in conventional livestock production systems. In the group with larger fields of simple shapes there was a relatively high percentage of acreage allocated to growing oil plants. In Polish conditions the presence of oil plants is a strong indication of intensification of arable system. This is because fields with rape plants are intensively managed by application of high-input practices. Intensive arable system tends to occur in larger fields because by economy of scale improvements in such conditions it is easier to overcome technological and economical constraints. However, it has been shown that increased fields can often lead to a loss of crop diversity and other components of arable ecosystems [Roschewitz et al. 2005, Tschamtké et al. 2005].

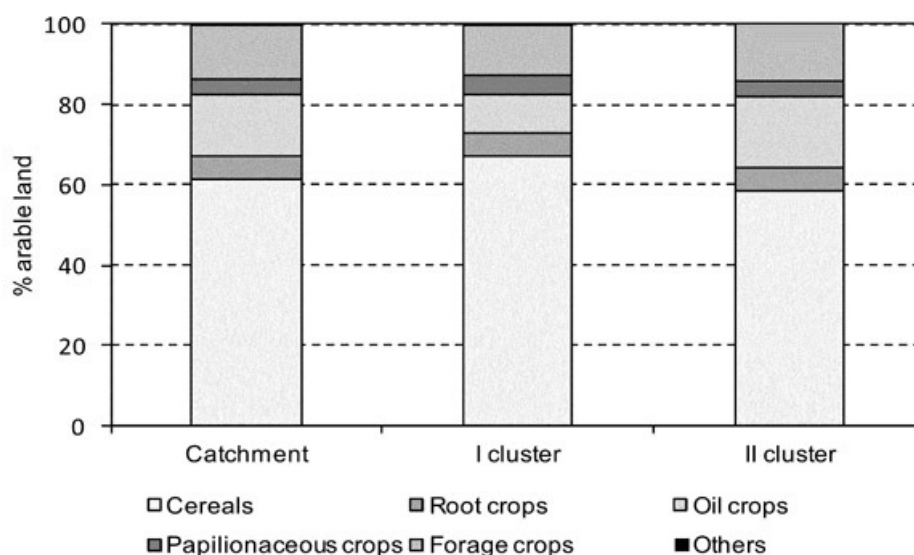


Fig. 3. Cropping pattern in the studied catchment and in the distinguished fields clusters

The distribution of mineral N fertilization of major crop categories between the two clusters of fields is shown in Figure 4. In cluster I, N fertilization of cereals was relatively homogeneous, falling into a relatively narrow range (60–90 kg ha<sup>-1</sup>). A wide array of N fertilization presented fields with cereals in the second cluster. However, over three-quarters of cereals area was fertilized with the N rate exceeding 90 kg N ha<sup>-1</sup>. The small variations in N fertilization were seen in large fields with root crops and with fodder plants, and to a lesser extent in oil crops. Area percentages of large crop fields fertilized with high N rates were markedly higher than in small fields of simple shape characteristic.

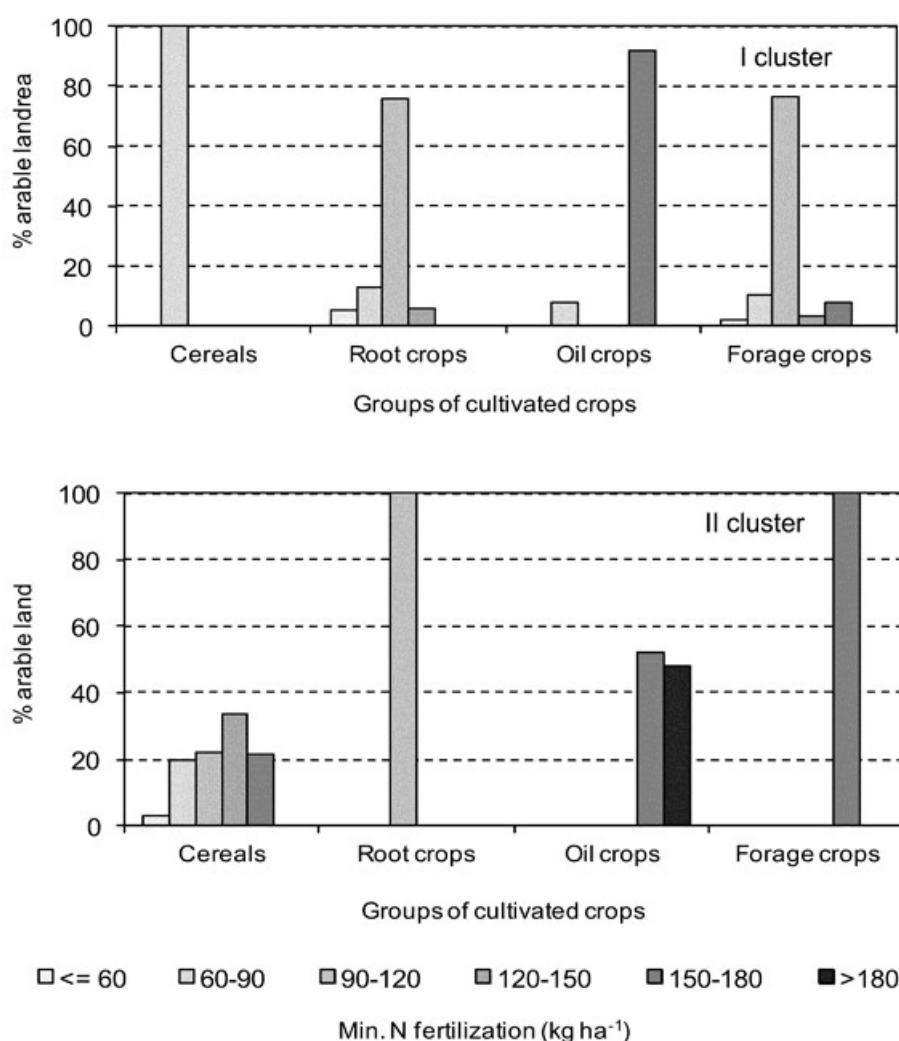
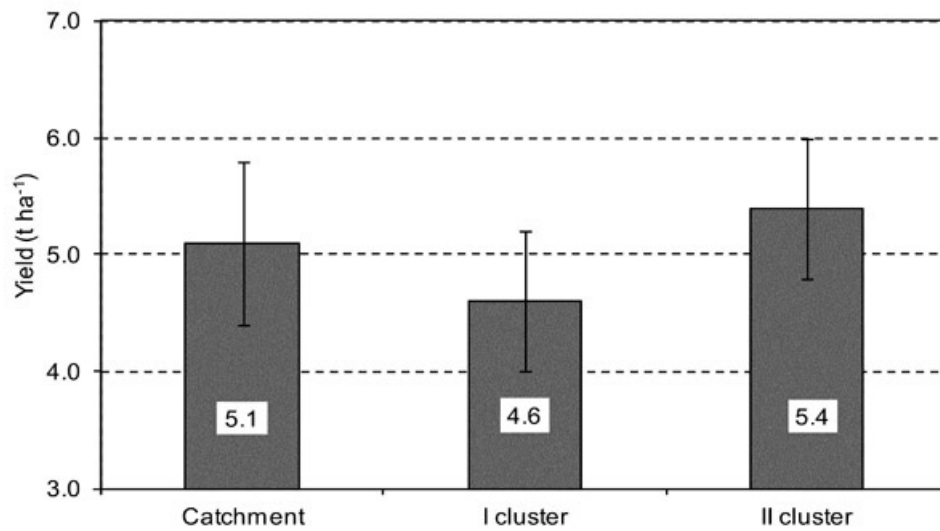


Fig. 4. Structure of mineral N fertilization for the groups of cultivated plants in the distinguished fields clusters (cluster I and II) in the studied catchment in relation to the cultivated area

Larger fields with simple boundary outlines (group II) had generally higher yields of winter cereals by an average of  $0.8 \text{ t ha}^{-1}$  compared to the smaller, more spatially complex fields, indicated as group I (Figure 5). Perhaps more intense management of larger fields, especially by applying more N fertilizers, can be a main factor in improving winter cereals yields. Benefits of lower N application in the group of small fields were linked with increased agronomic efficiency of this nutrient, defined as the ratio of the cereals yields to the rate of N fertilization (arithmetic mean), by nearly 50% compared to large area fields. The expected environmental impact of this could mean that the risk of N loss is markedly reduced in winter cereal fields belonging to cluster I both because of the generally lower level of N fertilization and because of its better utilization by plants.



**Fig. 5. Winter cereal yields (weighted means  $\pm$  weighted standard deviation) for all fields in the catchment and for the distinguished fields clusters**

Against the background of the analyzed data, marked quantitative differences were already found both in the total pool of N inflow and in the yields of winter cereals between the two analyzed spatial structures of fields in the catchment. An important issue would also be to assess a relationship between the heterogeneity of spatial structures and plant productivity. It can be appropriate therefore to determine the relationship in this regard, which would identify based on the model a general factor interaction effect. To explain the relation between variables a multiple regression model was used as is expressed by equation 1. Attempting to describe in a straightforward way the reasons for yield changes of winter cereals in the catchment a quantitative variable of N inflow to fields and a qualitative variable of spatial field structure were included in the model. The variable of spatial field complexity was considered in order to verify an existence of functional linkage of spatial field determinant with the plant productivity in this catchment, which seems hard to directly identify for agricultural landscapes composed of a relatively small number of uniform fields. Qualitative variable was introduced into the analysis by the construction of zero/unity dummy variables:  $X_0$  – is equal to 0 for observation data in the group I of fields,  $X_1$  – is equal to 1 for data in the group II of fields. The developed model was fitted with an  $R_2 = 0.39$  and the following coefficients:

$$Y = 3.783 (0.152) + 0.008(0.001) \text{ DNP} + 0.622(0.150) X_1 \quad (4)$$

where: Y – yield of winter cereals ( $\text{t ha}^{-1}$ ), DNP – supply of N to the fields ( $\text{kg ha}^{-1}$ ),  $X_1$  – group II, () – standard error.

Both N inflow to fields and field spatial heterogeneity were significant as explanatory factors of yield variability ( $P < 0.001$ ). Regardless of N supply significantly higher yields were achieved in the group II of fields in which the average yield per 1 ha was higher by more than 0.6 tons compared to the yields achieved in group I. Probably in this group, being characterized by more homogeneous and larger fields, there are favorable conditions from the side of large scale of operation for the use of modern, capital intensive technology inducing productivity changes. In light of these results it can be justified to hypothesize that the spatial conditions of fields in the investigated area are quality factors which originally are a reflection of existing structural limitation that prevent one from applying intensive crop production methods across the whole catchment.

Aside from considering spatial variability aspects in this catchment alone, it was substantiated to investigate complex relationship between land use, environmental variables and production intensity variables in the general population of farms, taking into account their entire agricultural area by inclusion of the fields located outside the catchment. Characteristics of relations between variables and farms are presented in two-dimensional space, using the biplot method (Figure 6). The first component explained 23% of the total variation. Overall two components accounted for 43% of the original data variance. The first component was strongly influenced by N mineral fertilization (NMN), the share of forages (% PAST) and livestock density (DJP). The results indicated that among the variables: N excess (NNADWYZKA), root crops share (% OKOP), forage share, livestock density and Simpson's Index (INDSIMPSON), expressing the diversity structure of the cultivable farm fields, there was a positive correlation. It follows from this that there is a group of farms, plausibly with dairy-oriented type of production, which besides more spatially diversified structure has a higher share of forages and which is often accompanied by the presence of large N excesses at field level. The second component was associated with the variables: share of cereals (%ZBOZ), share of arable

land in total area (% GO), grain yield (PLONZB), field size (WPOLA) and share of oilseeds (% OLEISTE). This component may represent the overall intensity of crop production. The presence of large size fields was associated with higher yields of cereals, higher shares of cereals and oilseeds in cropping area. The study revealed the importance of cereals in cropping structure in relation to the environmental variable of N surplus. Between the cereals percentage vs. N surplus and percentages of crop roots and forages there was a negative relationship. This implies that in areas with dominant share of cereals in cropland, lower N balances can be expected. Large saturation of agricultural area with cereals characterized farms with a lower degree of fields fragmentation. In terms of landscape spatial variability a large share of cereals in the cropping area is considered disadvantageous because dominance of one crop type in the agricultural landscape affects the biodiversity of agricultural ecosystems [Shennan 2008, Landis et al. 2008].

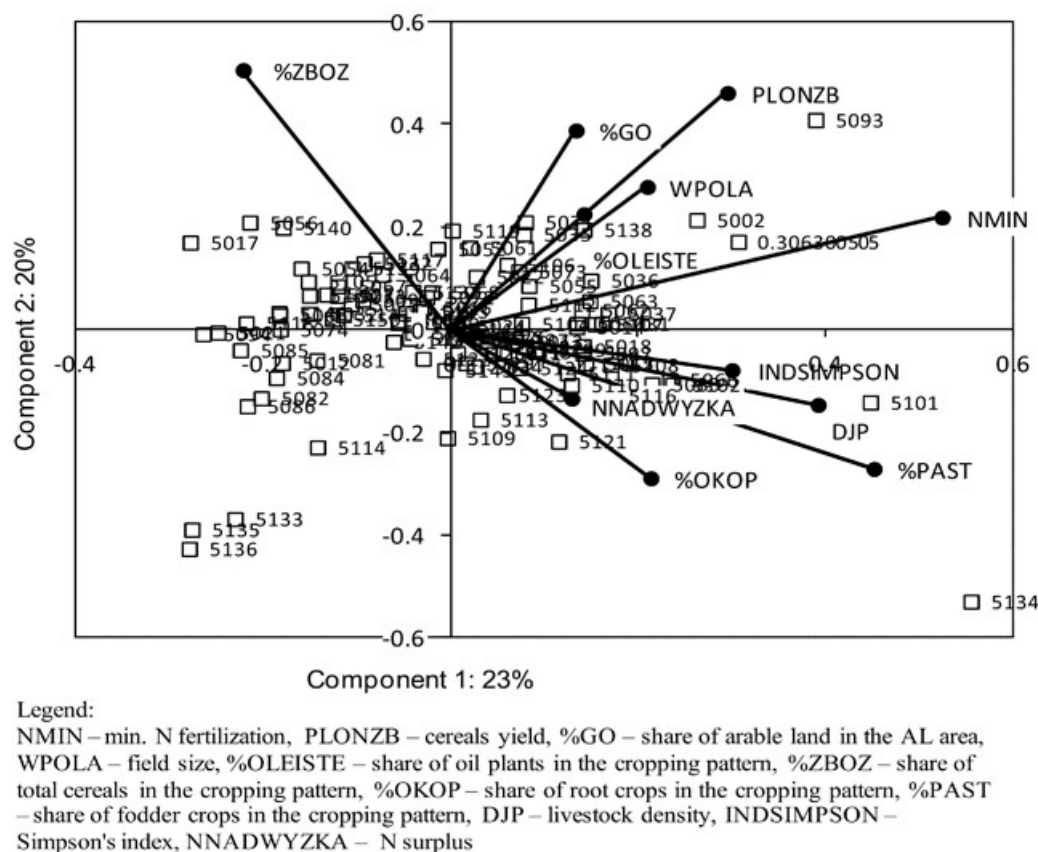


Fig. 6. Biplot diagram of principal components in relation to the analyzed variables and farms in the Wysok Ditch catchment

## CONCLUSIONS

Analysis of N surpluses at field level in the area of agricultural catchment requires the establishment of an extensive dataset with high spatial accuracy because it should take into account the aspect of spatial variation of N balances. On the basis of calculation of N balances for individual fields, by considering all identified sources of N supply, one can pinpoint separate areas at high risk of N loss into the environment through the processes of leaching and runoff. Averaging of N surpluses at the scale of a single farm can lead to oversimplification, because the variability of N surplus between fields can be blurred. For this reason, monitoring the environmental effects of N excesses in the agricultural catchment may be less effective because it is not possible to identify areas with particularly high loads of N. It was shown that the spatial fields structure in the studied catchment is symptomatic of field N surplus. In the group of small fields with a complexity of shapes, lower intensity of plant production processes occurred in comparison to the group of larger fields and simple shapes. Lower levels of N surpluses in the cluster of small fields can be explained against the background of differences in the amount of mineral N fertilization and a greater share of cereals in the cropping area in relation to the cluster of larger fields with more regular shapes. Spatial heterogeneity of fields and intensity of crop production were found to be related to N surpluses across the investigated catchment area. Complexity of spatial field structures within agricultural landscape may indicate to presence of differences in the intensity of agricultural land use and a large diversity of farms' specialization in the area. The occurrence of spatial relationships of N surpluses and intensities of land use indicates that the targeting of environmental protection schemes aimed at increasing the efficiency of N use, should focus both on the whole farm and on the level of agricultural landscape.

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