INTRODUCTION

For many years, issues related to the use of nitrogen in the broadly understood human activities have been simultaneously considered in the context of the negative impact of this element on the environment. Intensification of agriculture, guaranteeing increased production, leads at the same time to the dispersion of the components put into circulation. Estimates show that in farming areas of Europe the dispersion of nitrogen from soils is 10–50 times higher in comparison with non-agricultural land. Studies also show that about 90% of the emitted ammonia comes from agricultural sources (Parris, 1998). The type of agricultural production on the farm determines the level of impact on the environment. More nutrients, in the form of animal feed and mineral fertilizers, flow into livestock producing farms in comparison with farms engaged in crop production only. In addition, on animal farms there is often a surplus of manure produced there in relation to the size of the arable land owned by them.

In view of these facts, particular attention should be paid to the proper management of nutrients on farms with livestock production. The lack of comprehensive data on nutrient management in Polish agriculture and the many questions arising from the research and experience abroad had prompted us to undertake a detailed study in this area.

The aim of this study was to develop a model of nitrogen management on farms specializing in livestock production.

MATERIALS AND METHODS

The study was conducted on 20 farms located in 12 municipalities in the Mazowieckie province in central Poland in 2009–2012. A representative sample of farms was selected in collaboration with the Mazowieckie Agricultural Advisory Centre in Warsaw. The selected farms were divided, depending on the intensity and type of production, into organic farms and farms specializing in the production of dairy cattle, pigs or poultry (four types, each represented by five farms). The farmers who agreed to cooperate gathered, on a regular basis, information on crop and livestock production during each year of the study. The information was collected in the form of:

1. records of the products purchased and sold (records of the weight of mineral fertilizers, nutritive feed and bulky feed (succulent and dry) purchased by the farm, and of the plant and animal products sold),
2. records related to the fields in use (information on the surface area of the fields, types of crops, doses of mineral and natural fertilizers applied, the amounts of crops and aftercrops harvested),

http://www.degruyter.com/view/j/ssa (Read content)
3. animal feeding records (data on the type and quantity of feed given to the livestock on a monthly basis, both summer and winter feeding),
4. records of livestock trading (inventory data such as the age of the animals, purchase and sale dates, weight of the animals).

The nitrogen management model presented here was developed on the basis of the data recorded by the farmers and the results of analyses of samples of soil, manure, crop plants and bulky feed, which were collected directly on the analyzed farms in 2009–2011.

The collected soil samples were analyzed for: the amounts of available forms of phosphorus and potassium by Egner-Riehm method, magnesium by Schachtschabel’s method, and soil pH in KCl at 1 mol·dm$^{-3}$, by potentiometry.

The collected samples of manure, bulky feed produced on the farm, purchased feed and the harvested crops were analyzed for: dry matter content by oven-drying and weighing, total nitrogen content by Kjeldahl method.

On the basis of the data obtained from the farmers and the results of laboratory analyses nitrogen balances were calculated as ‘field surface balance’ and ‘farm-gate balance’, according to the methodology adopted by OECD (Organisation for Economic Cooperation and Development); also calculated was the efficiency of agricultural production on the individual farms expressed in cereal units (CU) per 1 kg of nitrogen applied on the farm (CU·kg$^{-1}$ N).

In order to determine the characteristics of the individual parameters, the basic descriptive statistics were used: mean, standard deviation, median, minimum-maximum, and the correlation matrix. Frequency distributions of a particular feature were shown in histograms.

The model was developed using multiple linear regression analysis carried out to the point at which the smallest significant number of variables was obtained (for $p \geq 0.05$) that explained to the greatest extent the variable $y$ expressed in CU·kg$^{-1}$ N in accordance with the backward stepwise method, using for that purpose Statistica 5.1. In order to explain how much of the total variability in the dependent variable was explained by the nitrogen management model described here, the corrected coefficient of determination ($R^2$) for polynomial regression was used.

RESULTS AND DISCUSSION

The population of farms included in the study varied in terms of the system of managing fertilizer components. The differences in the management resulted in the differences in the pH of the soils and the levels of available nutrients in them. On the other hand, high soil fertility determines the extent of utilization of fertilizer components by crop plants (Janssen, 2006). For this reason, knowledge of the chemical properties of soils is a very important element in the development of a nutrient management system. The properties of the soils concerned have been described in detail in previous articles (Szymaniska et al., 2011a, 2011b). Most of the analyzed soils were highly acidic or acidic, which is characteristic of Polish agriculture. The most soils of this type were found on farms specializing in dairy cattle production, and the least on organic farms. In terms of soil fertility with respect to the available forms of phosphorus, potassium and magnesium, the most soils with low and very low levels of these components were found on organic farms. By contrast, the dominant soils of poultry farms were very rich in these elements (Szymaniska et al., 2011a, 2011b). The type of animal production determined the structure of the crops grown on the farm. Crop structure affects the balance of nutrients, mainly nitrogen (Barszczewski et al., 2011), and that is why it was subjected to a detailed analysis (Table 1). In general, the crop structure of the analyzed farms was dominated by cereals (about 57%); the second largest were grasslands (about 23%), which were mainly found on cattle farms. The smallest share in the crop structure was that of root crops (about 6%) and legumes (an average of less than 5%). Leguminous crops were found primarily on organic farms.

The different types of farms differed in the intensity of livestock production ($INS_{an}$), which is a measure of livestock density expressed as livestock units per hectare of arable land (LU·ha$^{-1}$). According to the principles of Good Agricultural Practice, stocking density should not exceed 2 LU·ha$^{-1}$. If that is the case, the farm is able to produce the right amount of animal feed and utilize the resulting manure within the farm. The average livestock density in the analyzed population was 1.45 LU·ha$^{-1}$. It should be noted, however, that there was a poultry farm supporting more than 19 LU·ha$^{-1}$ (Table 1). The intensity of livestock production was positively correlated with the amount of nitrogen introduced into the soil with natural fertilizers ($Nat_N$) ($r = 0.53^*$), and with the amount of nitrogen entering the farm in the purchased animal feed ($PAF_N$) ($r = 0.7^*$). This indicates that on those farms there was a shortage of their own feed resulting from the mismatch between the size of the livestock population and the croplands owned, or the crop structure did not match the feeding needs of the animals (Table 2), which is further confirmed by a high positive correlation coefficient ($r = 0.69^*$) between $INS_{an}$ and the amount of nitrogen in the sold...
TABLE 1. Descriptive statistics of selected parameters of the analyzed farms

<table>
<thead>
<tr>
<th>Descriptive statistics</th>
<th>Farm soil characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH&lt;sub&gt;KCl&lt;/sub&gt;</td>
</tr>
<tr>
<td>Mean</td>
<td>4.73</td>
</tr>
<tr>
<td>Median</td>
<td>4.60</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.72</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.47</td>
</tr>
<tr>
<td>Maximum</td>
<td>7.14</td>
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</table>

Explanations: P, K – amount of available forms of phosphorus, potassium; C<sub>str</sub> – share of cereals in crop structure (%); L<sub>str</sub> – share of legumes in crop structure (%); G<sub>str</sub> – share of grasslands in crop structure (%); INS<sub>an</sub> – intensity of animal production (LU·ha<sup>-1</sup>); M<sub>N</sub> – nitrogen content in manure; B<sub>fs</sub>N – field surface nitrogen balance (kg N·ha<sup>-1</sup>); Min<sub>N</sub> – amount of nitrogen applied in mineral fertilizers (kg N·ha<sup>-1</sup>); Nat<sub>N</sub> – amount of nitrogen applied in natural fertilizers (kg N·ha<sup>-1</sup>); PAF<sub>N</sub> – amount of nitrogen in purchased animal feed (kg N·ha<sup>-1</sup>); SAP<sub>N</sub> – amount of nitrogen in sold animal products (kg N·ha<sup>-1</sup>); SPP<sub>N</sub> – amount of nitrogen in sold plant products (kg N·ha<sup>-1</sup>); B<sub>fg</sub>N – farm-gate nitrogen balance (kg N·ha<sup>-1</sup>).
A large number of data with a large N balance surplus (>60 kg N·ha\(^{-1}\)) is an undesirable occurrence, especially as the predominant soils of the analyzed farms were light soils susceptible to the leaching of nutrients. This is particularly important in the case of the nitrogen responsible for the eutrophication of surface waters, and besides, represents a financial loss for the farmer.

The surplus in the case of the farm-gate N balance was much larger. The distribution of the balances from that balance sheet (Fig. 2) shows that the largest number of objects fell within three ranges: 50–100, 150–200 and 0–50 kg N·ha\(^{-1}\). A relatively large number of objects was also in the range of 250–300 kg N·ha\(^{-1}\); those were farms that specialized in poultry production. The obtained amounts of the balance surpluses indicate significant retention of nitrogen within the farm and may also indicate significant losses of this element through the leaching of nitrates and emissions of ammonia.

The above characteristics of the parameters of the analyzed farms were used to develop a model of nitrogen management on farms that raise livestock at different levels of production intensity. Because of
TABLE 2. Correlation matrix – selected parameters of the analyzed farms (at p ≥ 0.05)

<table>
<thead>
<tr>
<th></th>
<th>pH_{KCl}</th>
<th>P_{mg.kg^{-1}}</th>
<th>K_{mg.kg^{-1}}</th>
<th>C_{sor}</th>
<th>R_{sor}</th>
<th>L_{sor}</th>
<th>G_{sor}</th>
<th>INS_{so}</th>
<th>M_{N}</th>
<th>B fertilizer</th>
<th>Min_{N}</th>
<th>Nat_{N}</th>
<th>PAF_{N}</th>
<th>SAP_{N}</th>
<th>SPP_{N}</th>
<th>BDO_{N}</th>
</tr>
</thead>
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<td>pH_{KCl}</td>
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<tr>
<td>P_{mg.kg^{-1}}</td>
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<tr>
<td>K_{mg.kg^{-1}}</td>
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<td>0.49*</td>
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<tr>
<td>C_{sor}</td>
<td>-0.24*</td>
<td>0.31*</td>
<td>0.13</td>
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<tr>
<td>R_{sor}</td>
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<td>0.19*</td>
<td>-0.48*</td>
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<tr>
<td>L_{sor}</td>
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<td>-0.01</td>
<td>-0.10</td>
<td>-0.14</td>
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<tr>
<td>G_{sor}</td>
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<td>-0.30*</td>
<td>-0.70*</td>
<td>0.07</td>
<td>-0.36*</td>
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</tr>
<tr>
<td>INS_{so}</td>
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<td>0.14</td>
<td>0.23*</td>
<td>-0.16*</td>
<td>-0.06</td>
<td>-0.24*</td>
<td></td>
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<tr>
<td>MN</td>
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<td>0.11</td>
<td>-0.11</td>
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<td>-0.02</td>
<td>0.15*</td>
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<td>B fertilizer</td>
<td>-0.33*</td>
<td>0.04</td>
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<td>0.40*</td>
<td>-0.36*</td>
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<td>-0.15*</td>
<td>0.19*</td>
<td>0.22*</td>
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<tr>
<td>Min_{N}</td>
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<td>0.24*</td>
<td>0.15*</td>
<td>0.45*</td>
<td>-0.17*</td>
<td>-0.09</td>
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<td>0.04</td>
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<td>-0.14</td>
<td>0.30*</td>
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<td>0.03</td>
<td>-0.10</td>
<td>0.53*</td>
<td>0.33*</td>
<td>0.39*</td>
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<td>PAF_{N}</td>
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<td>0.29*</td>
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<tr>
<td>SAP_{N}</td>
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<td>-0.03</td>
<td>0.37*</td>
<td>-0.19*</td>
<td>-0.12</td>
<td>-0.25*</td>
<td>0.15*</td>
<td>-0.07</td>
<td>0.03</td>
<td>0.01</td>
<td>-0.04</td>
<td>0.14</td>
<td></td>
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<tr>
<td>SPP_{N}</td>
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<td>0.21*</td>
<td>0.04</td>
<td>-0.07</td>
<td>-0.22*</td>
<td>0.69*</td>
<td>0.02</td>
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<td>0.52*</td>
<td>0.26*</td>
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<tr>
<td>BDO_{N}</td>
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<td>0.32*</td>
<td>0.24*</td>
<td>0.42*</td>
<td>-0.24*</td>
<td>-0.04</td>
<td>-0.30*</td>
<td>0.42*</td>
<td>0.19*</td>
<td>0.42*</td>
<td>0.49*</td>
<td>0.45*</td>
<td>0.74*</td>
<td>-0.44*</td>
<td>0.1</td>
<td>1</td>
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</tbody>
</table>

Abbreviations: see Table 1.

TABLE 3. Standard error of estimate for the directional coefficient (slope) of each independent variable in the model

<table>
<thead>
<tr>
<th>Variables</th>
<th>Intercept</th>
<th>R_{sor}</th>
<th>L_{sor}</th>
<th>G_{sor}</th>
<th>INS_{so}</th>
<th>M_{N}</th>
<th>Min_{N}</th>
<th>Nat_{N}</th>
<th>PAF_{N}</th>
<th>SAP_{N}</th>
<th>SPP_{N}</th>
<th>BDO_{N}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard error</td>
<td>0.0671</td>
<td>0.0024</td>
<td>0.0015</td>
<td>0.0009</td>
<td>0.0091</td>
<td>0.0117</td>
<td>0.0004</td>
<td>0.0006</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.0012</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: see Table 1.
the unfavourable relationship between the prices of the means of production and the prices of crops, as an indicator of the efficiency of nitrogen management it was decided to use the efficiency of production per kg of the component applied in the fertilizers and animal feed, i.e. the amount of plant and animal products produced, expressed in cereal units per kg of the component used (CU·kg⁻¹ N). Similar indicators had been adopted in the development of nutrient management efficiency on dairy farms (Schröder et al., 2005). This indicator was adopted as the dependent variable in our nitrogen management model. The average value of this indicator was 0.63 CU·kg⁻¹ N (Table 1). The coefficient of variation of this trait was high, reaching 82%, which was due to the differences in the intensity of production on the different types of farms.

Based on the multiple regression analysis performed stepwise, those parameters that did not determine the dependent variable were eliminated. In the end, there were 10 independent variables in the model (Equation 1).

Equation 1. Model of nitrogen management on farms specializing in livestock production, with $R^2 = 0.7$

$$y = 1.0142 - 0.0186 R_{str} - 0.0018 L_{str} - 0.0076 G_{str} + 0.2251 INS_{an} - 0.0047 M_N - 0.0011 Min_N + 0.0053 Nat_N - 0.0036 PAF_N - 0.0013 SAP_N - 0.0081 SPP_N$$

where:

Dependent variable:

$y$ – efficiency of agricultural production in cereal units per 1 kg of nitrogen applied on the farm (CU·kg⁻¹ N);

Independent variables:

$R_{str}$ – share of root crops in crop structure (%),

$L_{str}$ – share of legumes in crop structure (%),

$G_{str}$ – share of grasslands in crop structure (%),

$INS_{an}$ – intensity of animal production (LU·ha⁻¹),

$M_N$ – nitrogen content in manure,

$Min_N$ – amount of nitrogen applied in mineral fertilizers (kg N·ha⁻¹),

$Nat_N$ – amount of nitrogen applied in natural fertilizers (kg N·ha⁻¹),

$PAF_N$ – amount of nitrogen in purchased animal feed (kg N·ha⁻¹),

$SAP_N$ – amount of nitrogen in sold animal products (kg N·ha⁻¹),

$SPP_N$ – amount of nitrogen in sold plant products (kg N·ha⁻¹).

The above model indicates that among the different parameters of the farm a decisive role in determining the efficiency of nitrogen management in terms of cereal units obtained from 1 kg of applied nitrogen is played by: crop rotation and the crop structure associated with it; the amount of nitrogen brought to the farm with the purchased animal feed; the intensity of livestock production and digestibility of the feed indirectly associated with it (nitrogen content in manure); nitrogen dose levels in natural and mineral fertilizers; and also nitrogen outflow from the farm in the plant and animal products sold. The presence in the model of the crop structure on the farm results from the different nutritional requirements of the different groups of crop plants, which is reflected in different rates of nitrogen removal from the soil. The above model explains 70% of the variation in the efficiency coefficient expressed in CU·kg⁻¹ N ($R^2 = 0.7*$. Another measure of how well the model fits the empirical data is the standard error of estimate $S_e$, which is 0.29. This means that the values of the variable $y$ in CU·kg⁻¹ N, calculated on the basis of the above equation, differ from the empirical values by about ±0.29. Standard errors of estimation of the partial regression coefficients of each independent variable in the model are shown in Table 3. The largest error of estimate (about 35%) is for the nitrogen introduced with mineral fertilizers, while the smallest (4%) is for the intensity of livestock production.

CONCLUSIONS

1. The intensity of livestock production determines the efficiency of nitrogen management on the farm.

2. Among the four types of farms specializing in organic production and the production of dairy cattle, pigs and poultry, the largest balance surpluses, and thus the greatest potential losses of nitrogen, occurred on the farms that specialized in poultry production.

3. Farms with intensive animal production are characterized by a very large inflow of nitrogen in the form of purchased animal feed relative to the amount of nitrogen contained in the animal products sold. The difference is the amount of nitrogen retained in the livestock and the loss of nitrogen through leaching and gaseous emissions.

4. On the basis of the developed model it was shown that a decisive role in the determination of the efficiency of nitrogen management expressed in CU·kg⁻¹ N is played by: crop rotation; the intensity of animal production; the nitrogen content in manure; the amount of nitrogen in the purchased feed; the size of nitrogen doses in natural and mi-
eral fertilizers; and also nitrogen outflow from the farm in the plant and animal products sold.

5. The model explains 70% of the variation in the efficiency coefficient expressed in CUs per 1 kg N.

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LITERATURE


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