FUZZY TOPSIS METHOD APPLIED FOR EVALUATION OF MITIGATION STRATEGIES FOR GREENHOUSE GAS EMISSIONS FROM ABANDONED GRASSLAND

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Abstract: Most agricultural area lies under permanent grasslands (3488 M ha, or 69%). Grasslands and fertilized areas occupy about 20% of the Earth’s land surface generating considerable GHG emissions and increasing global climate change. Grassland compose 1.2 M ha, or 50% of agricultural lands in Lithuania. Accounting for GHG emission of grassland ecosystems may be important to evaluate and interpret measurements of fluxes at regional and ecosystem levels. Therefore biosphere-atmosphere interactions were investigated on a clay loam topsoil over silt loam (Calc(ar)-Endohypogleyic Luvisol) in different managed grassland ecosystems of Training farm of Lithuanian University of Agriculture in 2009 within the frame of the European Projects COST. Objective of this investigation was to determine impact of fertilizers, their rates and combinations on GHG emission and productivity of abandoned semi-natural sward and cultural pasture. GHG emission measurements were run in June-September, when meteorological conditions were optimal for intensive plant and soil biota physiological processes, in absence of frosts stress. Gradual decline of GHG fluxes was observed during vegetation, in accordance with decreasing supply of environmental components encompassing organic substrates, fertilizers, activity of microorganisms, as well as their interaction with humidity and temperature (HTC ranged from 2.0 to 0.9). There was strong correlation observed between mean $N_2O$, $CO_2$ and $CH_4$ emission during vegetation period on the one hand, and NPK ($r=0.9$, 0.8 and 0.9) with monominal nitrogen fertilizers ($r=0.8$ and 0.6) on the other. The fuzzy multi-criteria decision making method TOPSIS was applied when choosing the best compromise fertilizing regime. Therefore appropriate fertilizing rate for supporting soil fertility and low emissions rate should not to exceed $N_{60}P_{25}K_{50}$. Keywords: emissions, fuzzy TOPSIS, sustainability, grassland, fertilizing

Introduction

Human-inflicted greenhouse gas emissions affect the global temperature (IPCC, 2007). United Nations has summarized greenhouse gas (GHG) annual increase of 0.4 ($CO_2$); 0.6 ($N_2O$) and 0.25 % ($CH_4$). Therefore it is actual to reduce this main agent of climate change, i.e. GHG emissions in agricultural sector as well as in others activities. Grasslands (3488 M ha, or 69 %) occupy a large segment of global agricultural land (5023 M ha), consequently, measurement and prediction of GHG emissions from these ecosystems are of great importance (FAOSTAT, 2006). Furthermore, amount and composition of covering plant species impact considerably total GHG emission in grassland ecosystems (Raivonen et al., 2009). In Central Lithuania, like in other parts of central Europe, abandoned grasslands situated near woodlands are overgrown by shrubs and trees (Dzwonko and Loster, 2007). An increase in tree and shrub cover results in a decrease of the number and cover of grassland species and may lead to their local extinction within decades. Domestic political-economical circumstances have meant, that about 50% of grasslands (former pasture or arable land) have been abandoned and has been turning into natural habitats/climatic ecosystems during the last two decades in Lithuania (Balezentiene et al., 2010). In order to maintain soil fertility and imminent growing up with shrubs and trees, these abandoned, differently anthropogenized plots needs to apply extensive management, e.g. sustainable fertilizing, grazing, etc. (Vries et al., 2002) However, rising fertilizer use contributed to a number of environmental problems including an increase of GHG emissions (Groeningen et al., 2004; Lehuger et al., 2010). Moreover intensive recycling and often high rates of applied mineral fertilizers is expected to be significant pathway for contribution to share of global anthropogenic GHG emission share from agro sector (IPCC, 2007; Johnson et al., 2007). Therefore assessment of effects of various fertilizing rates and techniques on the gaseous emissions from abandoned grasslands should be based on research data (Kammann et al., 2008). Otherwise, agro ecosystems are represented by complex of multidimensional components thus making their evaluation and management rather complicated. Hence their evaluations require appropriate analysis techniques including mathematical methods (Baležentis et al., 2010). In order to address this context, it is necessary to move away from the assessment methods that have traditionally predominated in agro ecosystems management. Multiple criteria decision making (MCDM) methods are aimed at choosing the best alternative from finite set of alternatives with respect to certain objectives represented by respective criteria (Linkov et al. 2006; Lynam et al. 2007). More specifically, Roy (2005) presented the following pattern of MCDM problematique: 1) $\alpha$ choosing problem – choosing the best alternative; 2) $\beta$ sorting problem – classifying alternatives into relatively
Materials and Methods

The measurements were conducted on two sites: abandoned for more than 20 years grassland and intensively managed cultural pasture have been situated at Aleksandras Stulginskis University (54º52' N, 23º50' E), Kaunas district, during vegetation period of 2009. The site is located in 5-6 hardiness zone (Peel et al., 2007) of temperate climate (C) with moderate warm summer and moderate cold winter (Lithuanian climate, 2007). Mean annual temperature ranges between 5.5-7.5°C with annual precipitation of 670 mm. Total solar radiation inflow amounts 3600 MJ m⁻² in Lithuania. The site soil was clay loam topsoil over silt loam (Calc(ar)i)-Endohypogleyic Luvisol; FAO/UNESCO, 1997). Humus horizon was 25 cm deep. The N (ammonium saltpetre 34.4% N) and NPK (ammonium saltpetre 34.4% N + granulated superphosphate 19% P₂O₅ + potassium chloride 60 % K₂O) application scheme of 9 treatments of semi natural sward (>20yrs abandoned former sown sward): Control (0); N₆₀; N₁₂₀; N₁₈₀; N₂₄₀; N₁₈₀P₁₂₀; N₁₈₀K₁₅₀; N₆₀P₄₀K₅₀; N₁₈₀P₁₅₀K₁₅₀. P and K were applied before plant vegetation in early spring. N fertilizer was applied two times: end of April and after 1st cut (beginning of July) in all grasslands. Fresh mass (FM) weighting (g 0.2 m⁻² per treatment) and drying (105°C) were used to determine grassland productivity (g m⁻²) and obtain dry mass (DM, %). Grassland botanical composition was determined on harvested vegetation.

GHG (CO₂, N₂O and CH₄) emissions were monitored by the static chamber method (Hutchison, Livingston, 1993) using opaque circular chambers (0.05 m²), with 6 replicates per treatment. Cylindrical steel collar (20 cm high and 43 cm diameter) were inserted into the soil to a depth of 6 cm. Two collars and chambers were placed in each treatment. The collar frames remained in the soil and were open to the atmosphere between samplings, except when removed for tillage and sowing. During the measurements the chambers were closed with an airtight lid simultaneously in all treatments. Chamber air was sampled 3 times in one hour interval period. Gas fluxes were measured on 4 different dates in grasslands.

The measurements were carried out 2 or 3 weeks after fertilizer application every month between June and September in absence of frost stress. The gas samples were analyzed in the laboratory by infrared gas analyzer (MGA3000) calibrated separately for each gas using ML-800 gas standard (2 atm). Gas samples were analyzed on the same day evaluating volume concentrations (ppm) of trace gases. Daily net exchange (mg h⁻¹ m⁻²) of CO₂, CH₄ and N₂O in agro ecosystem was calculated by integrating the 60-minute fluxes determined by the meteorological measurements over each day.

Thermal and irrigation conditions during vegetation period were characterized by sum of monthly precipitation (Pr) and active air temperature (T) (>10 ºC), accordingly to commonly used in Europe G. Selianinov (1928) hydrothermal coefficient (HTK) (Coufal, 1987). High rates of hydrothermal coefficient (HTC=2.0 and 4.0) indicated moisture abundance in June and August, but it was optimal in July (HTC=1.6), and too dry (HTK=0.9) in September 2009.

In order to evaluate the most optimal management way of agro ecosystems the fuzzy set theory and fuzzy TOPSIS for group decision making were applied. Zadeh (1965) introduced the use of fuzzy set theory when

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dealing with problems involving fuzzy phenomena. Noteworthy, fuzzy sets and fuzzy logic are powerful mathematical tools for modelling uncertain systems. A fuzzy set is an extension of a crisp set. Crisp sets only allow full membership or non-membership, while fuzzy sets allow partial membership. The theoretical fundament of fuzzy set theory are overviewed by Chen (2000).

In a universe of discourse \( X \), a fuzzy subset \( \tilde{A} \) of \( X \) is defined with a membership function \( \mu_{\tilde{A}}(x) \) which maps each element \( x \in X \) to a real number in the interval \([0; 1]\). The function value of \( \mu_{\tilde{A}}(x) \) resembles the grade of membership of \( x \) in \( \tilde{A} \). The higher the value of \( \mu_{\tilde{A}}(x) \), the higher the degree of membership of \( x \) in \( \tilde{A} \) (Keufmann and Gupta, 1991). Noteworthy, in this study any variable with tilda will denote a fuzzy number.

A fuzzy number \( \tilde{A} \) is described as a subset of real number whose membership function \( \mu_{\tilde{A}}(x) \) is a continuous mapping from the real line \( \mathbb{R} \) to a closed interval \([0; 1]\), which has the following characteristics: 1) \( \mu_{\tilde{A}}(x) = 0 \), for all \( x \in (-\infty; a] \cup [c; \infty) \); 2) \( \mu_{\tilde{A}}(x) \) is strictly increasing in \([a; b]\) and strictly decreasing in \([d; c]\); 3) \( \mu_{\tilde{A}}(x) = 1 \), for all \( x \in [b; d] \), where \( a, b, d, \) and \( c \) are real numbers, and \(-\infty < a \leq b \leq d \leq c < \infty \). When \( b = d \) a fuzzy number \( \tilde{A} \) is called a triangular fuzzy number represented by a triplet \((a, b, c)\).

Triangular fuzzy numbers will therefore be used in this study to characterize the alternatives. The membership function \( \mu_{\tilde{A}}(x) \) is thus defined as:

\[
\mu_{\tilde{A}}(x) = \begin{cases} 
0, & x < a, \\
\frac{x - a}{b - a}, & a \leq x < b, \\
\frac{x - c}{b - c}, & b \leq x < c, \\
1, & x > c. 
\end{cases}
\] (1)

In addition, the parameters \( a, b, \) and \( c \) in (1) can be considered as indicating respectively the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event (Tolrak et al., 2011).

Let \( \tilde{A} \) and \( \tilde{B} \) be two positive fuzzy numbers (Liang, Ding 2003). Hence, the main algebraic operations of any two positive fuzzy numbers \( \tilde{A} = (a, b, c) \) and \( \tilde{B} = (d, e, f) \) can be defined in the following way (Zavadskas, Antuchevičienė 2007): Addition \( \oplus \):

\[
\tilde{A} \oplus \tilde{B} = (a, b, c) \oplus (d, e, f) = (a + d, b + e, c + f);
\] (2)

Subtraction \( \ominus \): \( \tilde{A} \ominus \tilde{B} = (a, b, c) \ominus (d, e, f) = (a - d, b - e, c - f) \); (3)

Multiplication \( \otimes \): \( \tilde{A} \otimes \tilde{B} = (a, b, c) \otimes (d, e, f) = (a \times d, b \times e, c \times f) \); (4)

Division \( \oslash \): \( \tilde{A} \oslash \tilde{B} = (a, b, c) \oslash (d, e, f) = (a \div d, b \div e, c \div d) \). (5)

The vertex method will be applied to measure the distance between two fuzzy numbers. Let \( \tilde{A} = (a, b, c) \) and \( \tilde{B} = (d, e, f) \) be two triangular fuzzy numbers. Then, the vertex method can be applied to measure the distance between these two fuzzy numbers:

\[
d(\tilde{A}, \tilde{B}) = \frac{1}{3} \left[ (a - d)^2 + (b - e)^2 + (c - f)^2 \right].
\] (6)

Fuzzy numbers can be applied in two ways when forming the response matrix of alternatives on objectives. First, fuzzy numbers can represent the values of linguistic variables (Zadeh 1975) when deciding either on the method can be applied to measure the distance between these two fuzzy numbers. For example, if there are costs “approximately equal to $200” estimated, the sum can be represented by triangular fuzzy number (190, 200, 210). Moreover, the fuzzy numbers can embody expected rate of growth. For example, if there is level of unemployment of 5 per cent with expected growth of 10 per cent, a triangular fuzzy number (5, 5.5, 6.1) can summarize these characteristics. Similarly, crisp number \( x \) with uncertainty of 5 per cent can be represented by a fuzzy number (0.95x, \( x \), 1.05x). As for time series data, a fuzzy number can represent the dynamics of certain indicator during past \( t \) periods:

\[
(\tilde{X}(a_1) - 0.5s(a_1), \tilde{X}(a_1), \tilde{X}(a_1) + 0.5s(a_1)).
\] (7)
where \( \overline{x}(a_i) \) and \( s(a_i) \) stand for mean and standard deviation of certain indicator respectively. Krohling and Campanharo (2011) developed the following procedure for fuzzy group decision making. First of all, we have a group decision makers \( G = \{M_1, M_2, \ldots, M_L\} \). This group can encompass various stakeholders interested in the analyzed phenomenon. Each of them is assigned with coefficient of significance \( \alpha_i \in [0,1] \), where \( i = 1,2,\ldots,L \), such that \( \sum_{i=1}^{L} \alpha_i = 1 \). Moreover, each of the decision-makers is attributed with appropriate significance vector \( W^i = (w^i_1, w^i_2, \ldots, w^i_n) \), \( l = 1,2,\ldots,L \) with \( n \) being the number of criteria. The coefficients of significance can be obtained by applying AHP method (Dagdeviren et al., 2009), entropy method (Huang, 2008), ameliorated nominal group or Delphi methods (Brauers and Zavadskas, 2010).

The initial decision matrix \( \tilde{P} = (p_{ij}, p_{2i}, \ldots, p_{ni}) \) is formed with \( i = 1,2,\ldots,m \) being the number of alternatives and \( j = 1,2,\ldots,n \) being the number of criteria respectively. Consequently, the initial matrix is normalized by applying the following procedure:

\[
p'_{ij} = \frac{p_{ij}}{\sqrt{\sum_{j=1}^{n} p_{ij}^2}}, \quad p'_{ij} = \frac{p_{ij}}{\sqrt{\sum_{i=1}^{m} p_{ij}^2}}, \quad \forall i,j
\]

As a result, the normalized matrix \( \tilde{P}^* \) is formed. Consequently, the weighted normalized decision matrix for each decision maker is calculated:

\[
\hat{P}^* = \begin{pmatrix}
w[1]_{i1} & \cdots & w[1]_{in} \\
\vdots & \ddots & \vdots \\
w[m]_{i1} & \cdots & w[m]_{in}
\end{pmatrix},
\]

with \( l = 1,2,\ldots,L \) being the number of decision makers. \( L \) decision matrixes are therefore formed. The positive ideal solution \( A^+ \) as well as negative ideal solution \( A^- \) are found for each decision maker:

\[
A^+ = (p_{ij}^+, \ldots, p_{ni}^+), \forall l,
\]

\[
A^- = (p_{ij}^-, \ldots, p_{ni}^-), \forall l,
\]

where

\[
p_{ij}^+ = (\max_{j} \hat{p}_{ij}, \min_{j} \hat{p}_{ij}, j \in J_1),
\]

\[
p_{ij}^- = (\min_{j} \hat{p}_{ij}, \max_{j} \hat{p}_{ij}, j \in J_2),
\]

with \( J_1 \) and \( J_2 \) being sets of benefit and cost criteria respectively. Then Eq. (6) is employed in order to obtain the distances of each alternative from the positive ideal solution for the \( l \)-th decision maker:

\[
d_i = \sum_{j=1}^{n} d(p_{ij}^+, \hat{p}_{ij}, \forall i,l)
\]

Similarly, the distances from the negative ideal solution are calculated in the following way:

\[
d_i = \sum_{j=1}^{n} d(p_{ij}^-, \hat{p}_{ij}, \forall i,l)
\]

Finally, the relative proximity of the \( i \)-th alternative to the positive ideal solution for the \( l \)-th decision maker is found:

\[
c_i = \frac{d_i}{d_i + d_i'}, \forall i,l
\]

The higher the value of \( c_i \), the more proximate the \( i \)-th alternative is to the positive ideal solution for the \( l \)-th decision maker. These results are summarized in the weighted relative-proximity matrix \( C = c_{il} = c_i \cdot \alpha_i \), for \( i = 1,2,\ldots,m \), \( l = 1,2,\ldots,L \), and further processed with traditional TOPSIS method. In this case, the positive ideal and the negative ideal solutions denoted respectively as \( A^+ \) and \( A^- \) are identified in the following way:

\[
A^+ = (\max_{i=1}^{m} c_i, \ldots, \max_{i=1}^{m} c_i)
\]

\[
A^- = (\min_{i=1}^{m} c_i, \ldots, \min_{i=1}^{m} c_i)
\]

The \( n \)-dimensional Euclidean distance method is then applied to measure the distances of each alternative from the positive-ideal solution and the negative-ideal solution:

\[
S_i = \left( \sum_{i=1}^{m} (x_i - c_i)^2 \right)^{0.5}, \text{for } i = 1,2,\ldots,m.
\]
with $c_i^+$ and $c_i^-$ being obtained from Eq. (17) and Eq. (18) respectively. Finally, the relative similarity to the positive-ideal solution is calculated (proximity to positive and remoteness to negative values):

$$c_i = \frac{s_i^-}{s_i^- + s_i^+},$$

where $c_i \in [0,1]$ with $i = 1, 2, \ldots, m$. The best alternative can therefore be found according to the preference order of $C_i$.

### Results and Discussion

Basically, the process of decision making is composed of decision makers, alternatives and criteria. In this study, there will be three approaches defined, each representing specific stakeholders. The investigated fertilizing regimes represent the alternatives. Finally, here two groups of criteria are considered, namely GHG emissions (cost criteria) and yield indicators (benefit criteria). CO$_2$, CH$_4$, N$_2$O emissions were evaluated at certain periods during the investigation period. Hence the mean volumes as well as standard deviations of these emissions were estimated and turned into fuzzy numbers according to Eq. (7). The remaining indicators of fresh mass (g m$^{-2}$), dry mass (g m$^{-2}$), and part (%) of grass (G) + legume (L) found in the harvest were translated into fuzzy numbers with 5% uncertainty. Table 1 summarizes the initial decision matrix.

Three approaches were considered in the analysis, namely those of farmers, environmental agencies, and holistic one. These three approaches can be perceived as three decision makers. Farmers seek to maximize the output of production, hence the importance of yield criteria is stressed. Environmental agencies seek to mitigate the pollution, and hence pay most of attention for minimizing the GHG emissions in stands. The holistic approach considers each of criteria equally important. Hence, two significance vectors $\alpha$ were formed. By changing the importance weights of the decision makers (ecologic, agro economic and holistic) and choosing second considers all the three approaches equally important. Hence, two significance vectors $\alpha$ were formed. Three scenarios were defined: the first one pays the most of attention to farmers’ needs, whereas the second considers each of criteria equally important. Three approaches were therefore formed (Table 2).

Moreover, two scenarios were defined: the first one pays the most of attention to farmers’ needs, whereas the second considers each of criteria equally important. Hence, two significance vectors $\alpha$ were formed. Three scenarios were therefore formed (Table 2). Consequently, the initial decision matrix was normalized according to Eq. (9). The positive as well as negative ideal solutions were hence found by employing Eq. (10) and Eq. (11).

### Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>CO$_2$, ppm</th>
<th>CH$_4$, ppb</th>
<th>N$_2$O, ppm</th>
<th>FM, g m$^{-2}$</th>
<th>DM, g m$^{-2}$</th>
<th>G+L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MIN</td>
<td>MIN</td>
<td>MIN</td>
<td>MAX</td>
<td>MAX</td>
<td>MAX</td>
</tr>
<tr>
<td>Control</td>
<td>122.871; 192.45; 262.029</td>
<td>0.03; 0.036; 0.043</td>
<td>1.225; 1.526; 1.827</td>
<td>909.625; 957.5; 1005.375</td>
<td>180.69; 190.2; 199.71</td>
<td>66.5; 70; 73.5</td>
</tr>
<tr>
<td>$N_{120}$</td>
<td>531.92; 790.236; 1048.551</td>
<td>0.028; 0.04; 0.052</td>
<td>1.456; 1.774; 2.092</td>
<td>847.875; 892.5; 937.125</td>
<td>193.61; 203.8; 213.99</td>
<td>50.35; 53; 55.65</td>
</tr>
<tr>
<td>$N_{240}$</td>
<td>637.635; 724.534; 811.433</td>
<td>0.02; 0.025; 0.03</td>
<td>1.742; 1.863; 1.984</td>
<td>952.375; 1002.5; 1052.625</td>
<td>223.345; 235.1; 246.855</td>
<td>71.25; 75; 78.75</td>
</tr>
<tr>
<td>$N_{180}P_{120}$</td>
<td>766.697; 874.506; 982.316</td>
<td>0.027; 0.032; 0.037</td>
<td>1.895; 2.28; 2.665</td>
<td>1444; 1520; 1596</td>
<td>182.97; 192.6; 202.23</td>
<td>66.5; 70; 73.5</td>
</tr>
<tr>
<td>$N_{180}K_{150}$</td>
<td>592.775; 643.457; 694.14</td>
<td>0.03; 0.038; 0.045</td>
<td>1.33; 1.586; 1.843</td>
<td>1615; 1700; 1785</td>
<td>366.89; 386.2; 405.51</td>
<td>85.5; 90; 94.5</td>
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<tr>
<td>$N_{180}P_{40}K_{50}$</td>
<td>983.428; 1261.542; 1539.65</td>
<td>0.03; 0.038; 0.045</td>
<td>1.693; 2.521; 3.349</td>
<td>1287.25; 1355; 1422.75</td>
<td>325.09; 342.2; 359.31</td>
<td>76; 80; 84</td>
</tr>
<tr>
<td>$N_{180}P_{120}K_{150}$</td>
<td>1057.368; 1499.019; 1940.67</td>
<td>0.036; 0.045; 0.054</td>
<td>2.414; 2.694; 2.974</td>
<td>78880.4; 83032; 87183.6</td>
<td>470.725; 495.5; 520.275</td>
<td>85.5; 90; 94.5</td>
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<tr>
<td>$N_{180}P_{40}K_{350}$</td>
<td>632.263; 879.987; 1127.71</td>
<td>0.032; 0.034; 0.036</td>
<td>1.093; 1.889; 2.686</td>
<td>2869; 3020; 3171</td>
<td>786.315; 827.7; 869.085</td>
<td>92.15; 97; 101.85</td>
</tr>
</tbody>
</table>

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Table 2.

<table>
<thead>
<tr>
<th>Scenario I</th>
<th>Scenario II</th>
<th>Approaches</th>
<th>CO₂, ppm MIN</th>
<th>CH₄, ppb MIN</th>
<th>N₂O, ppm MIN</th>
<th>FM, g m⁻² MAX</th>
<th>DM, g m⁻² MAX</th>
<th>G+L, g m⁻² MAX</th>
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<tr>
<td>0.5</td>
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<td>Agro economic</td>
<td>0.08</td>
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<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>0.25</td>
<td>0.33</td>
<td>Environmental agencies</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>0.25</td>
<td>0.33</td>
<td>Holistic</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
</tbody>
</table>

The calculations of distances of each alternative from these solutions, according to Eq. (14) and Eq. (15), enabled to apply Eq. (16) and thus evaluate the relative proximity of each alternative to the positive ideal solution with respect to each of approaches. The results are visualized in Fig. 1.

Fig. 1. Fuzzy evaluation of grassland fertilizing according to different approaches

As we can see, the most promising fertilizing alternative according to both agro economic and holistic approaches is that of N₆₀P₄₀K₅₀. However, N₁₈₀P₁₂₀ is the most preferable one in the view of environmental agencies’ approach due to the lowest emission rates.

The two scenarios with different importance of the three approaches (i. e. groups of stakeholders; see Table 2) were evaluated by employing Eqs. (16)–(21) (Triantaphyllou, 2000). The results are presented in Fig. 2. The results suggest the existing convergence in choosing the best alternative: fertilizing rate N₆₀P₄₀K₅₀ is the most suitable according to both of scenarios. That could be explained by low fertilizer assimilation capacity of plant species established in semi natural grassland. Indeed it is more attractive for stakeholders of agro economic approach due to sufficient FM and DM yield. According to the both scenarios, N₁₈₀P₁₂₀K₁₅₀ could be considered the second-best option, which, in turn, is more attractive for the remaining stakeholders. This high fertilizer rate determined not only the highest yield of grasslands, but also the biggest GHG fluxes and management expenses. Therefore this treatment could be chosen in some circumstances, when seeking high productivity in short time etc.

Fig. 2. Summarized evaluation of grassland fertilizing according to different scenarios

Conclusions

In this study fuzzy TOPSIS method for group decision making to tackle multicriteria decision problems affected by uncertainty and taking into account the preferences of the decision makers was successfully applied. This method allows finding the best alternative of abandoned grassland amelioration by the way of fertilizing and thus ensuring both mitigation of GHG emissions and maximization yield indices. For this case study, we used 7 fertilizing ratios (and Control), three decision approaches (ecologic, agro economic and holistic) and two
scenarios (I and II) to illustrate the method. The results suggest the existing convergence in choosing the best alternative: fertilizing rate $N_{50}P_{50}K_{50}$ is the most suitable according to both of scenarios with respect to all decision approaches.

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