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Profiles of small-scale dairy farms assessed by socioeconomic and farm management practices: a case study from Poland

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Abstract

Agricultural systems vary worldwide due to location, socioeconomic conditions, and management practices. Understanding the patterns and key factors that lead to differences between farms is crucial to providing the best support for their development. In our study, we interviewed farmers who operate small-scale dairy farms (with 1-5 cows) in a major agricultural region of Poland specifically, the voivodships Małopolskie and Podkarpackie, to understand how socioeconomic factors and farm management practices shape the diversity of farm profiles, and we evaluated our results using cluster analysis. Our findings confirmed the diversity among small-scale farming systems, allowing the identification of three distinct farm profiles. One of these clusters reflects part-time farmers characterized by low agricultural incomes, another long-standing peasant or hobby farms, while the smallest cluster referred to more professionalized agricultural systems. The key factors that characterized the different farm profiles were related to animal production (i.e. grazing time), infrastructure (i.e. manure storage facilities), farm size (i.e. land area), farming practices (i.e. mineral fertiliser use) and farmer's experience. The analysis also identified various socioeconomic factors that influenced the prospects for the continuity of different farm profiles, pointing out the need to devise support policies very specifically addressing the respective needs.

Keywords: farm diversity, smallholders, cluster analysis, grazing, manure management, milk production,

Introduction

Small-scale farms, defined by area, make up the vast majority of all farms worldwide[1]. It is estimated that between 475 to 500 million farms have an area of less than 2 hectares (ha) (84% of the total number of farms), while farms with an area greater than 50 ha constitute only 1% of the world's farms[2,3]. Additionally, livestock farming plays a crucial role within global agriculture, with the dairy sector relying on approximately 290 million dairy cows worldwide[4]. However, in high-income countries the number of small-scale farms has been decreasing for years in favour of large, more specialised ones[5,6]. Specifically, in the European Union (EU), the number of all farms dropped by around 37% from 2005 to 2020, resulting in the loss of 5.3 million farms, of which 87% were farms under 5 ha[6]. The most significant changes occurred in the new member states that joined the EU in 2004 (Poland and Hungary) and 2007 (Romania and Bulgaria)[6]. One of the most profound alterations in the period between 2005 and 2020 in farm structure was noted in Poland with a loss of 1.2 million farms (47 % of all farms), of which ca. 40% were farms with an area under 5 ha[6].

To date, the EU Member States recognise the importance of small-scale farms and support their viability and sustainability[7]. It is particularly important to emphasise that small-scale farms provide employment and help reduce poverty, particularly in less developed regions[8,9,]. Additionally, they often offer positive externalities, including greater adaptability to local conditions, stronger ties to their communities, and the ability to produce artisanal products[10–12]. Finally, small- and medium-sized agricultural systems exhibit greater diversity of cultivated crop species and wild biodiversity at both the farm and landscape scales compared to large-scale farming operations[13].

With regard to small-scale family farms, economic pressures such as rising input costs and stagnant sale prices endanger their profitability[14–16]. Moreover, they are often limited in their access to innovation, making it harder for them to compete with larger, more technologically advanced farms[17]. In the dairy sector, a growing trend toward production concentration and specialisation has further intensified these challenges[18]. Larger dairy operations often benefit from economies of scale and can more easily adopt specialised production practices, which improves their efficiency and lowers costs. However, recent findings revealed relationship between social coherence and environmental performance of small-scale farms[19]. They indicated that social well-being of farmers constitutes strong capital, which enables them to more readily adopt pro-environmental practices which, in turn, can lead to long-term economic benefits[20]. Therefore, incorporating social determinants of farmer quality of life into farm performance analysis is critical for comprehending farm operations and projecting their future viability. Research on the synergistic relationship between these social factors and conventional measures of farm structure and management remains limited, yet holds the key to developing more effective farm strategies.

In 2023, Poland had a dairy cow population that exceeded 2.2 million animals, making it the third-largest cow's milk producer in the EU, producing 15.5 million tonnes of milk, after Germany (34.0 million tonnes) and France (23.9 million tonnes)[21,22]. Based on the latest agricultural census conducted in 2020, the vast majority (71%) of the dairy cows was part of herds ranging from 20 to 200 animals, making up nearly 35% of all dairy holdings[23]. Small-scale farms (with up to 5 dairy cows) constituted 29% of all dairy farms, but included only 3.4% of the dairy cow population, thus having a small contribution to national milk production. However, taking into account the number of holdings, Poland had the second-largest number of smallholder farms with 1–5 dairy cows (50,350 holdings) in the EU, surpassed only by Romania with 231,290 holdings[23].

Small-scale dairy farms in Poland already apply strategies to improve their economic resilience, such as diversifying operations and adopting new technologies. In this direction, economic concerns remain the primary focus, while fewer strategies directly address social and environmental challenges[24]. However, due to the significant heterogeneity among small-scale farms in Poland, their future trajectories can vary, with carrying out investments, others maintaining current operations, and some opting for closure[25]. The primary factors influencing the development of these farms can be attributed to either external determinants, such as EU or national funding, or internal ones, including the capacity of farmers to engage in entrepreneurial activities.

Farms with a professional operational focus demonstrate higher economic viability, investments, and innovations. In contrast, farms classified as “dual occupation” or “hobby” operations prioritise securing public financial support and contributing public goods provision[26]. The European Common Agricultural Policy (CAP) has enabled the transformation of some small-scale farms into more modern and economically resilient entities. This is attributed to the support provided for their modernisation. Specifically, some farmers used aid funds to construct or upgrade farm buildings and modernise their machinery, facilitating growth in production and enhancing their competitiveness in the market[27]. Future trajectories for small farms in Poland and other countries may follow various paths. From the further development and growth, the continuation of small-scale operations, to the integration of both agricultural and non-agricultural activities, or even in some cases, farm termination[25].

One of the main challenges in the development of effective and optimal policies is the identification of the specific needs of the target group. In this sense, small-scale agriculture is highly diverse, reflecting the unique geospatial, biophysical, environmental, socioeconomic, and cultural contexts of different regions[27]. Even within Europe, there are various typologies and classification systems for small farms to better understand their current status, identify their needs and develop optimal solutions that support their sustainability. These solutions must address the social, environmental and economic dimensions, which are the main pillars of sustainable development[28–32]. In this sense, one of the important factors determining the directions of agricultural support policies is the geospatial and administrative differentiation of agricultural systems, among which the size of the farm plays an essential role[29,31,32].

The diversity of small-scale farms, here defined as those with less than 5 ha or fewer than 9,600 Euro of standard gross margin, which equals 8 Economic size units (ESU)[33] has drawn significant attention due to their socioeconomic characteristics. This focus has led to the identification of five different farm types: i) peasant farms, ii) diversified businesses, iii) specialised businesses; iv) new enterprise, and v) part-time farms at the European level, each with varying production motives, resources, and development prospects[29]. In Poland, the types of peasant, part-time and new enterprise farm types were found to be the most common, a trend also observed in Romania and, to some extent, in Latvia[29]. Studies specific to Poland further revealed that non-commercial farms, characterized by low income and turnover, and operated by farmers deeply rooted in tradition and strongly attached to agriculture, dominate the small farm group[34]. The existing typologies have focused primarily on the size of farms, but did not account for differences that may arise from specialisation in the production of specific products, such as grains, fruits, or cattle breeding. This highlights the need to develop more nuanced classification systems that incorporate production-specific factors, including scale, management practices, market integration, and the unique challenges faced by farmers producing particular products. Such an approach could provide greater clarity in characterising farm diversity, enhance our understanding of small farms carrying out animal production, and better inform policy interventions. Expanding the typology to include farm management and product-specific factors could further elucidate the role of traditional practices and local contexts in shaping the sustainability and resilience of these farms.

To this end, this study aims to assess the diversity within small-scale farms in Poland – specified by housing of 1-5 dairy cows – by adopting a comprehensive typologies that move beyond farm structural and economic data. Specifically, we identify typologies for these farms based on a multi-dimensional approach that incorporates socioeconomic factors and farm management practices, with a particular emphasis on farmers' social profiles and extent of market orientation – dimensions often overlooked by conventional economic classifications – alongside farm conditions, management practices, and milk production operations. First, we characterize the surveyed farms to analyse structure and operational characteristics of the small-scale dairy sector. Next, farm profiles are determined using clustering analysis to segment the sample into distinct typologies with special attention to key features differentiating the clusters. Finally, we prioritize the variables that contribute most significantly to the diversity of the identified farm typologies based on a decision tree analysis.

Methods

Survey design and data collection

The data were collected in 2022 using a survey method based on face-to-face interviews with farmers. The questionnaire consisted of 99 questions, of which 60 offered predefined (closed) answer options and 39 were open-ended questions requesting specific information and opinions. Each interview was conducted in person at the farmer’s premises, with the interviewer directly interacting with the participant. The farm was represented by its owner, who was also the person performing most of the agricultural work. The interviewer asked the questions and recorded the responses in the questionnaire form. Completing the interview took approximately two hours. Additional information about the interviews can be found in a separate study[19].

The study focused on two south-eastern regions of Poland, the Małopolskie and Podkarpackie voivodships, where small-scale dairy farms are prevalent, with 87–89% of holdings keeping no more than five cows (Fig. 1a). These regions also have the smallest utilized agricultural area (UAA) per farm (Fig. 1b), which makes farm expansion particularly challenging. The voivodships were selected for the study because they represent the highest concentration of small dairy farms in Poland, a factor that strongly shapes the specific character of milk production in this part of the country. Historically, these areas featured smaller, more fragmented farms and received less systematic state investment in agricultural modernization than other Polish regions[20]. The sample initially included 50 farmers, purposely selected based on the criterion that they operated family farms housing no more than five dairy cows. Initial contacts were provided by regional Agricultural Advisory Centers (AACs) in the Małopolskie and Podkarpackie voivodships, which selected farmers and first obtained their explicit permission before sharing contact information with the research team. After surveying the farmers indicated by the AACs, the snowball sampling method was applied—subsequent participants were identified through recommendations from previously interviewed farmers who met the same selection criteria (owning a family farm located in one of the two voivodships selected for the study and keeping no more than five dairy cows). The sample was evenly distributed between the two regions, with 25 surveys conducted in each voivodship.

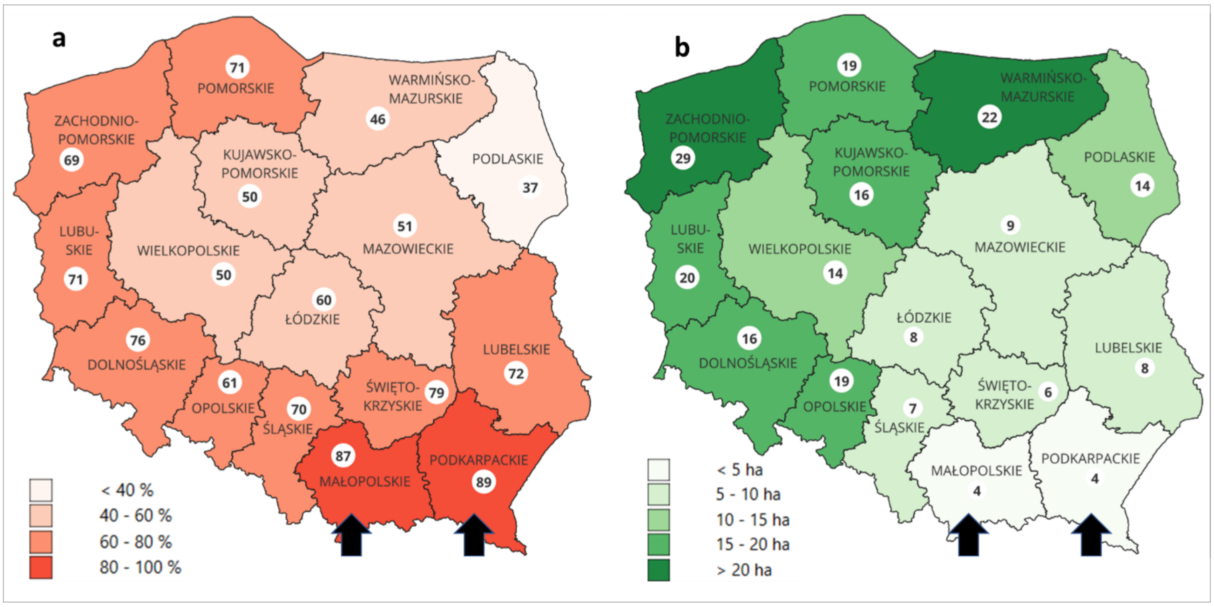

Fig. 1 Distribution of small farms (up to 5 dairy cows) in the total number of dairy farms (a) and average utilized agricultural area (UAA; in ha) per farm (b). Black arrows indicate the investigated regions. These maps were developed based on materials (shp file) from the Polish State Geodetic and Cartographic Resource (PZGiK) licensed under CC BY 4.0. (Pol. Opracowano na podstawie materiałów państwowego zasobu geodezyjnego i kartograficznego). Maps were created using QGIS v.3.34.0 (https://qgis.org/).

The study methodology and implementation techniques were designed by a sociologist on the research team with extensive experience in survey-based research within agricultural and rural studies. The questionnaire was constructed to align with the specific research objectives and the analytical framework adopted for this study. It does not utilize copyrighted scales requiring external permission. To ensure content validity, the instrument was subjected to a rigorous review by a panel of experts in agricultural and environmental disciplines. This process ensured that the items accurately represented the research constructs and that the thematic sections were logically structured for the target population.

The study adhered to the principles of sociological research as defined in the American Sociological Association (ASA) Code of Ethics[35]. The research methodology and instruments were developed in accordance with the Declaration of Helsinki and institutional ethical standards and were formally verified for ethical compliance by the Committee for Sociological Research Ethics of the University of Zielona Góra. The study was conducted in strict adherence to the General Data Protection Regulation (GDPR), ensuring full participant anonymity and the protection of personal data.

The questionnaire used in this study was designed to collect comprehensive socioeconomic and farm management data to facilitate the identification of farm typologies carrying out dairy animals. The information was organised into two main categories: socioeconomic characteristics and farm management practices. A full list of the variables included in the assessment, together with detailed descriptions, is available in Table S1 (Supplementary Information).

The socioeconomic component of the questionnaire was designed to profile farmers by examining various personal and operational factors, including demographics (gender of the farmer, general education level, specialized agrarian education, and years of farm experience), satisfaction and profitability (level of financial satisfaction and professional fulfilment), milk production objectives and future plans (primary purpose and profitability of milk production, plans related to the continuity of the farm).

The second component focused on variables that characterise farm size, livestock management, and field operations. These encompassed livestock practices with key aspects of animal husbandry and welfare, such as grazing duration and feeding practices, buildings' infrastructure, including information on their improvement and space for animals, and manure management infrastructure. The availability and capacity of manure storage, including manure piles for solid manure and tanks for liquid manure, were also considered. Furthermore, field management practices were evaluated, including the availability of agricultural machinery, the application of mineral fertilisers and practices for incorporating manure into the soil after field application.

Determination of farm profiles

Farm diversity was studied with non-supervised clustering methods using the whole set of variables listed in Table S1 (Supplementary Information). One of the investigated farms, despite maintaining only two dairy cows, exhibited a markedly larger utilized area of 90 ha. This significant deviation from the typical characteristics of the sample led to the exclusion of this farm from this analysis.

To ensure comparability between variables, the numerical data were first standardized using z-score normalization ($z=(x-\mu)/\sigma$, where 'z' is the z-score, 'x' is the raw value, 'μ' is the mean of the dataset, and σ is the standard deviation of the dataset) to prevent magnitude imbalances. Likewise, an evaluation of the data set was carried out to test the feasibility of the clustering trend using the Hopkins statistic parameter (H), which yielded a score of H=0.66, indicating a strong tendency for the data to cluster with statistical significance[36]. Parameters and methods used in this and the subsequent steps of the cluster analysis are shown in Table S2 (Supplementary Information).

Since the data set contained numerical and categorical variables, a *k-prototype* algorithm was employed for cluster classification[37], using the *k-modes* package in Python version 3.11.7[38]. To determine the optimal number of clusters, a heuristic approach was adopted, testing cluster counts ranging from 1 to 9[39]. Although the cost declined monotonically with increasing k, the reduction in loss beyond k = 3 was marginal (Fig. S1 in Supplementary Information) relative to the added complexity. More importantly, the three-cluster solution yielded distinct, interpretable farm profiles.

Clustering analysis was configured to ensure accurate and consistent results. First, the gamma parameter (), which influences how the algorithm groups the data, was automatically determined (=0.5) based on the dataset's characteristics. This adaptive approach helped optimise the clustering process. To maintain consistency and reproducibility, a fixed random state of 852 was established. For initialising the cluster centres and selecting optimal starting points for the clusters, the Cao method was used because it helps to select good starting points for the clusters, leading to more accurate and efficient results, especially when dealing with categorical data[40]. Additionally, a multiple-iteration approach (10 iterations) was conducted with different centroid seeds, to increase the likelihood of achieving the optimal grouping. Furthermore, the number of *k-mode* iterations per single run was defined at 100, enabling the refinement of the clusters.

Determination of key variables describing farm profiles

To determine the most significant factors differentiating between clusters, non-parametric statistical tests were employed, since not all of the continuous variables were normally distributed, as evaluated with Shapiro-Wilk test (recommended for small sample sizes with p value set at 0.05), which precluded the use of parametric tests[41]. For quantitative variables, the Kruskal-Wallis test was used. Significant results ($p<0.05$) were analysed with a post-hoc Mann-Whitney U test and Bonferroni correction set a $p=0.017$ to identify significant differences between individual clusters. For categorical variables, the Chi-square test of independence was applied. To account for potential bias in small sample sizes, Yates' correction was used. To indicate significant differences between clusters, pairwise chi-square tests were performed with Bonferroni correction set at $p=0.017$.

To evaluate and interpret the clustering results, a decision tree classifier was implemented (Table S3)[42]. This method provided a transparent, rule-based framework for identifying the variables most influential in distinguishing clusters, thereby assessing the internal consistency of the clustering solution. Its ability to handle mixed data types, both numerical and categorical, without strong distributional assumptions makes it particularly suitable for this dataset. The approach thus complements the unsupervised clustering with a supervised, interpretable validation that enhances the reliability of the results. A decision tree is a hierarchical rooted structure used for classification tasks. It begins with a root node and branches into internal and leaf nodes. Each internal node represents a decision based on an attribute, splitting the instance space into distinct sub-spaces. The leaves or terminal nodes, assign a class label or a probability distribution over classes. Classification is performed by traversing the tree from the root to a leaf, following the decision rules at each internal node. Each test in the internal nodes evaluates an attribute or a range of values for numeric attributes, effectively partitioning the data. Decision trees can handle nominal and categorical attributes, making them versatile for various classification problems. For tree generation, the categorical variables were first converted using a one-hot encoding to ensure compatibility with the model. Before finalising the tree, Leave-One-Out Cross-Validation (LOO-CV) was applied, producing an accuracy of 0.79, demonstrating the model's reliability[42].

The final decision tree was generated using the whole data set (Table S1). Two principal hyperparameters were modified to limit the model's complexity. Hyperparameters are pre-training configuration of the model to establish how it will learn and generalise, helping to guide the training process.

The maximum depth of the decision tree was set to 3, as determined through preliminary testing that balanced model interpretability and performance. Shallower trees (depth <3) failed to capture sufficient structure in the data, while deeper trees led to overfitting and reduced clarity of interpretation. Therefore, a depth of 3 was selected as the optimal compromise between explanatory simplicity and classification accuracy. This constraint avoids high complexity during training, reducing overfitting tendency and improving interpretability. Second, the Gini impurity criterion was used to analyse the quality of splits by assessing how well each one separates the data into homogeneous groups. Lower impurity indicates better separations. All other hyperparameters were left at their default settings. The decision tree model was constructed using the sklearn package (version 1.5.0) in Python version 3.11.7.[42].

Results

Socioeconomic and farm performance characteristics

The farm owners were represented by men (31 cases) or women (18 cases) (Fig. 2a), who predominantly had 25-30 years (yrs) of experience (EXPER) as a farmer (Fig. 2b). Most of the respondents declared that they had no specialized agrarian education (EDU_FORM) (36 responses) (Fig. 2c). The average daily milk production of one dairy animal (MILK_PROD) ranged between 10 and 20 litres per cow and day (L cow^{-1} day^{-1}) (Fig. 2d). This milk was used (MILK_PURP) for own needs and sales (26 responses) or for its own needs only (20 responses) (Fig. 2e).

The majority of respondents (31 farmers) identified their milk production enterprise (MILK_PROF) as non-profitable (Fig. 2f). Nevertheless, most of them (33 respondents) were (very) satisfied with their lives as farmers (SATISF_PROF) (Fig. 2g) and most of them (31 respondents) would want to continue this profession (CHANG_PROF) (Fig. 2h). However, the financial satisfaction of the farmers (SATISF_FIN) was mainly at an intermediate level (Fig. 2i) because the income from work on a farm was most often combined with hired work (23 respondents), pensions (23 respondents) and social assistance benefits and allowances (23 respondents) (detailed data are available in[19]: Fig. S2).

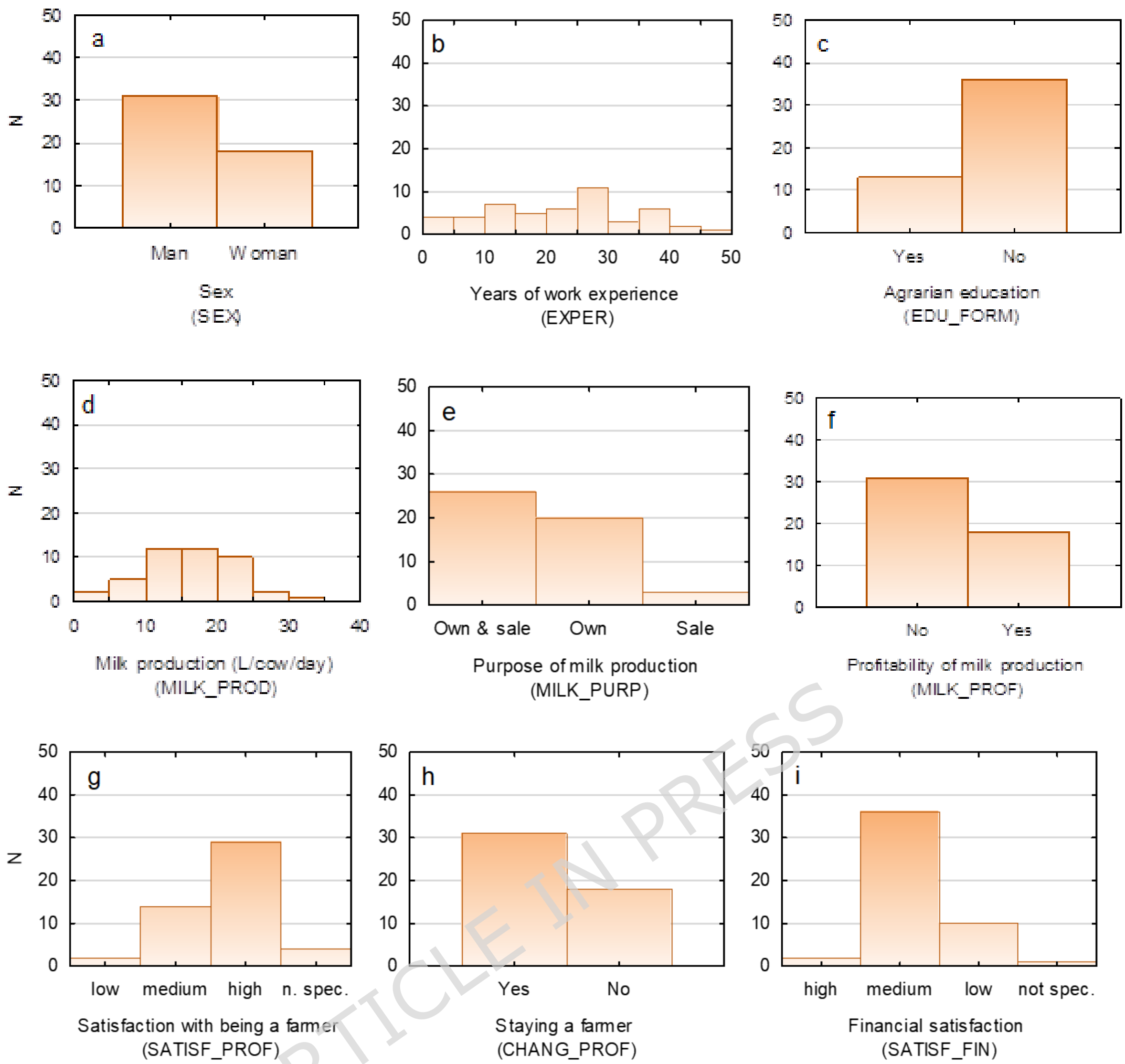

Fig. 2 Response distribution among farmers considering: sex (a), years of experience in agriculture (b), specialized agrarian education (c), average daily milk production per cow (d), milk production purpose (e), estimation of profitability of milk production (f), satisfaction with being a farmer (g), staying a farmer in case of changing profession (h), financial satisfaction from a running a farm (i).

Farming system characteristics

The farms had on average 3 cows, ranging from 1 to 5 animals (DAIRY_ANIM) (Fig. 3a). The own used land (AREA-o) was on average 5 ha, ranging from 1 to 20 ha (Fig. 3b), and an average farm had no leased land (AREA-l), but some minor part of the farmers leased it from other farmers up to 20 ha (Fig. 3c). Regarding the most common farm conditions and animal-related practices, the animals spent between 0 and 5670 hours (h) annually on pastures (GRAZ), with an average of 2160 hours per year ($h\ yr^{-1}$) (Fig. 3d).

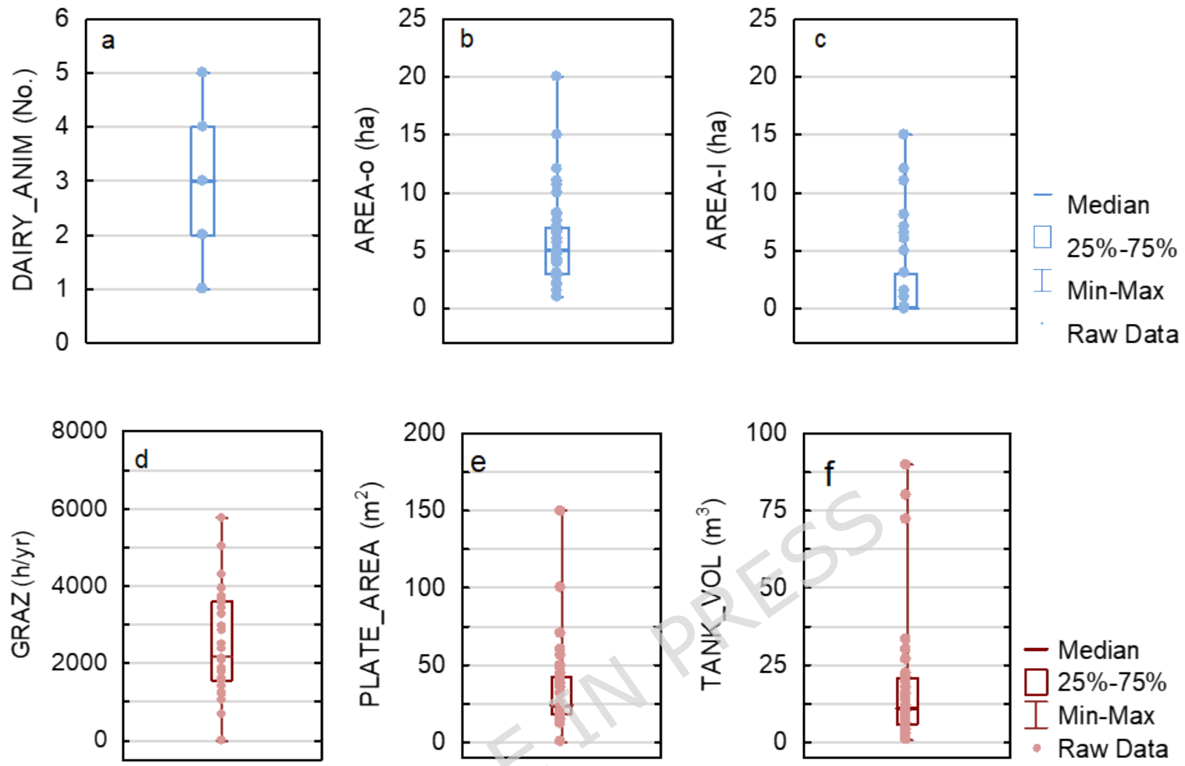

Fig. 3 General characteristics of investigated farms expressed as distribution of: (a) dairy cows (DAIRY_ANIM); (b) own utilized land (AREA-o); (c) leased land (AREA-l); (d) the length of annual grazing (GRAZ); (e) plate area for solid manure storage (PLATE_AREA); (f) tank volume for liquid slurry storage (TANK_VOL).

The vast majority of farms (96%) had tie-stall system (see detailed data in[19]). However, half of the respondents reported improved conditions for animals in buildings (BUILD) (Fig. 4a), including the animal space (ANIM_SPACE) ranging from 2 to 4 square meters (m^2) or more (Fig. 4b), and straw bedding in all farms. As all farms represented solid manure systems (see detailed data in Fig. 2g in[19]) with natural runoff of liquid manure during the storage stage. Plates were present to store solid manure (MAN_PLATE) in 44 farms (Fig. 4c). This manure was stored on concrete plates with areas extending up to 150 m^2 (PLATE_AREA) (Fig. 3e). Liquid manure stored in closed concrete tanks (TANK_VOL) with volumes reaching 90 m^3 (Fig. 3f). Most farmers also declared having agricultural machinery (MACH) (Fig. 4d), but few used it to incorporate solid manure (SOLID_PLOW) into the soil (Fig. 4f). Most farmers did not use mineral fertilisers (MIN_FERT) on their fields (Fig. 4e).

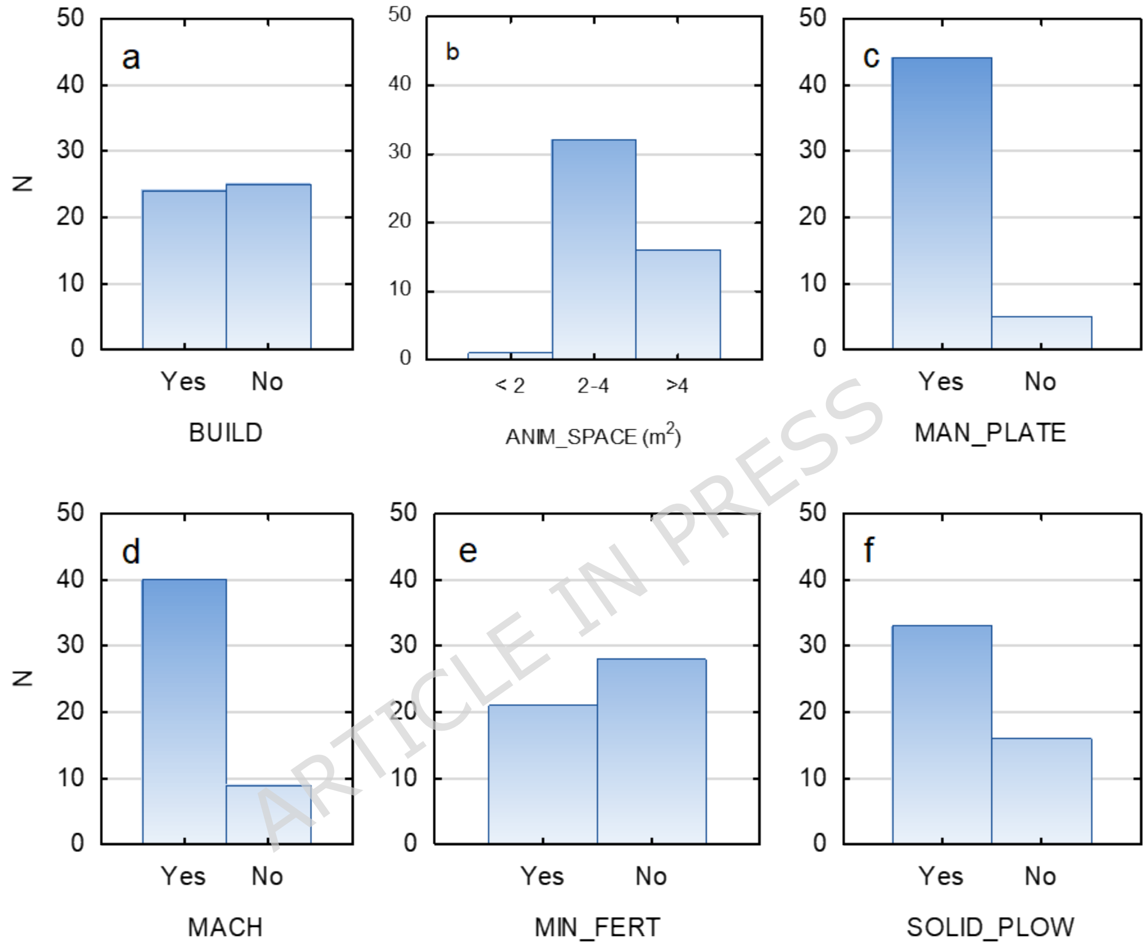

Fig. 4 Housing conditions and manure management practices presented as a shares of: (a) improved animal conditions in buildings (BUILD); (b) animal space in barns (ANIM_SPACE); (c) presence of manure plates (MAN_PLATE), (d) presence of farm machinery (MACH), (e) use of mineral fertilizers (MIN_FERT); and (f) incorporation of solid manure into the soil.

Profiles of small family-owned dairy farms

The applied clustering approach allowed to identify three farm groups and enabled the identification of features characterising distinct farm profiles (Table 1).

Most of the farms belonged to Cluster A (22 farms, representing 45% of the group being discussed). Farmers in this cluster generally lacked specialized agrarian education (82%) and reported the shortest period of agricultural experience (19 years on average). A significant portion of them would change their profession (CHANG_PROF) if the opportunity arose (41%). These farms had the highest average milk production of 20 L cow^{-1} day^{-1}, but most farmers considered it to be unprofitable (77%). Consequently, the majority produced milk for their own consumption (55%), while a smaller share combined self-supply and sale (32%). Only a few produced milk exclusively for sale (13%). Regarding animal welfare, most farms lacked improved buildings (64%) and did not have sufficient space for their animals (68%), but performed the longest grazing period, averaging approximately 3600 h yr^{-1}. Finally, Farms in this cluster were characterized by a small average area of own land (4.9 ha) and no leased land. While the majority did possess agricultural machinery (91%), they had the smallest facilities for storing manure: an average plate area for solid manure of 20 m^2 and a tank volume for liquid manure of 9.5 m^3.

The farms belonging to Cluster B were also numerous, representing 41% of the total sample (20 farms). Farmers in this cluster had the highest proportion on women (45%). They reported the longest agricultural experience (33 yrs), yet a high proportion lacked specialized agrarian education (75%). Despite their experience, these farmers showed the highest level of clear dissatisfaction with their financial situation (25%) and high readiness to change profession (40%). Furthermore, the majority (65%) was uncertain about the future succession and continuity of their farms. Considering milk production and market orientation, cluster B was distinguished by the lowest declared milk production overall (approximately 14 L cow^{-1} day^{-1}). However, most farmers viewed milk production as profitable (55%). The vast majority (85%) produced milk for both, their own consumption and for sale, while the remainder produced milk only for their own consumption (15%). None of the farms produced milk solely for sale (0%). Regarding animal welfare and husbandry, this cluster exhibited the highest proportion (70%) with a small building area for dairy cows, but with a moderate proportion (55%) in improved buildings. Also, dairy animals were grazed in a moderate time (approximately 1800 h yr^{-1}).Farms in this cluster also had the smallest own land area (4.55 ha on average) and no leased land, similarly, as in Cluster A. However, unlike in Cluster A, this group showed more extensive infrastructure related to animal production, such as larger storage facilities for both solid (28.5 m^2) and liquid manure (13.5 m^3), which allowed one to keep large amounts of manure for longer periods. Also, mineral fertilizers were used by fewer farmers (30%) in this cluster than in any other. It is also worth mentioning that solid or liquid manure after spreading on the fields were practiced by 55% and 5%, respectively, which was the lowest result among all clusters. The potentially hindering practices for manure management practices could be the fact that this cluster had the highest percentage of farms (30%) without machines.

Cluster C was the least numerous, with only 7 farms representing 14% of the total sample. Farmers in this cluster were mostly represented by men (86%), demonstrated the strongest educational background (57%), the strongest willingness to stay in the sector (86%). Notably, all farmers were satisfied with their job (86% satisfied and 14% very satisfied) and most of them (71%) had a plan for farm continuation. While their financial satisfaction was higher compared to other clusters, the overall result remained relatively low (14% satisfied). Regarding milk production, these farms achieved moderate values (15 L cow^{-1} day^{-1}). Unlike other clusters, the vast majority of farms in this group produced milk exclusively for their own needs (71%) and only small proportion (29%) combined it for own needs and for sale. The dairy animals had the shortest grazing time (1560 h yr^{-1} on average). However, these farms provided better conditions in the barns, evidenced by the highest proportion (43%) of area greater than 4 m^2 per animal and improved buildings (71%). The farms in this cluster had a considerably larger area of both own (8 ha) and leased (6.53 ha) arable land compared to the farms in other clusters. This group also had considerably better infrastructure for manure management, with the largest manure plates (37.5 m^2 on average) and tanks (15 m^3 on average). Regarding practices, most farmers utilized solid and liquid manure by incorporating them directly into their fields: 100% and 43%, respectively. Unlike other clusters, all (100%) used mineral fertilizers in the fields.

Table 1 Response frequencies (%) for qualitative variables and average values for quantitative variables within the clusters (A, B, C). Statistically significant differences between clusters are highlighted in bold, with significance levels indicated by asterisks: * for p≤0.05 and ** for p≤0.005.

Variable (code)	Response	Cluster A	Cluster B	Cluster C
Social farmer's profile				
CHANG_PROF	no yes	59 41	60 40	86 14
EDU_FORM	yes no	18 82	25 75	57 43
EXPER*	**years**	**19**^{a}	**33**^{b}	**22**^{a,b}
SEX	woman man	36 64	45 55	14 86
PLAN_FARM*	**yes** **no** **I don't know**	**55** **14** **32**	**35** **0** **65**	**71** **0** **29**
SATISF_FIN	satisfied more or less satisfied dissatisfied	5 77 18	0 75 25	14 71 14
SATISF_PROF	dissatisfied neither satisfied, nor satisfied very satisfied	9 36 45 9	0 30 65 5	0 0 86 14
Milk production and market orientation				
MILK_PROD*	**in L/cow/day**	**20**^{a}	**13.8**^{b}	**15**^{a,b}
MILK_PROFI	profitable not profitable	23 77	55 45	29 71
MILK_PURP**	**own needs** **own needs and sales** **mainly for sale**	**55** **32** **14**	**15** **85** **0**	**71** **29** **0**
Animal husbandry and welfare				
ANIM_SPACE	=< 4 m^2 > 4 m^2	68 32	70 30	57 43

BUILD	yes no	36 64	55 45	71 29
FEED_ORIG[#]	Fully farm-produced Own concentrate & forage purchased Own forage & concentrate purchased	68 5 32	80 0 20	86 0 14
GRAZ**	**h/yr**	**3600**	**1800[a]**	**1560[a]**
OTH_ANIM	yes no	18 82	20 80	29 71
REM_FREQ	Less than daily Once a day Twice a day Three times a day	0 5 77 18	5 5 75 15	0 0 100 0
Farm conditions, infrastructure and practices				
AREA-l**	**ha**	**0[a]**	**0[a]**	**6.53**
AREA-o	ha	4.9	4.55	8
LIQ_PLOW	yes no	23 77	5 95	43 57
MACH	yes no	91 9	70 30	86 14
MIN_FERT**	**yes** **no**	**36[a]** **64**	**30[a]** **70**	**100** **0**
PLATE_AREA*	**m^2**	**20[a]**	**28.5[b]**	**37.5[a,b]**
SOLID_PLOW*	**yes** **no**	**68[a]** **32**	**55[a]** **45**	**100** **0**
TANK_COV	concrete no cover other	23 5 73	30 0 70	71 0 29
TANK_VOL	m^3	9.5	13.5	15

[#] - option „concentrate & forage purchased" was not present in the sample, therefore not considered for the analysis.
a, b - different superscript letters indicate statistically significant differences between clusters (clusters sharing a letter are not statistically different).

Key features determining farm diversity

Using the decision tree approach, key variables influencing the classification of farm types were determined (Fig. 5). The most influential feature was the time the animals spent grazing (GRAZ), followed by the leased land area (AREA-l), the size of the infrastructure for storage of solid manure (PLATE_AREA) as well as the length of farmer's experience in agriculture (EXPER). Each class (representing each cluster) was characterised by a specific combination of conditions in all features.

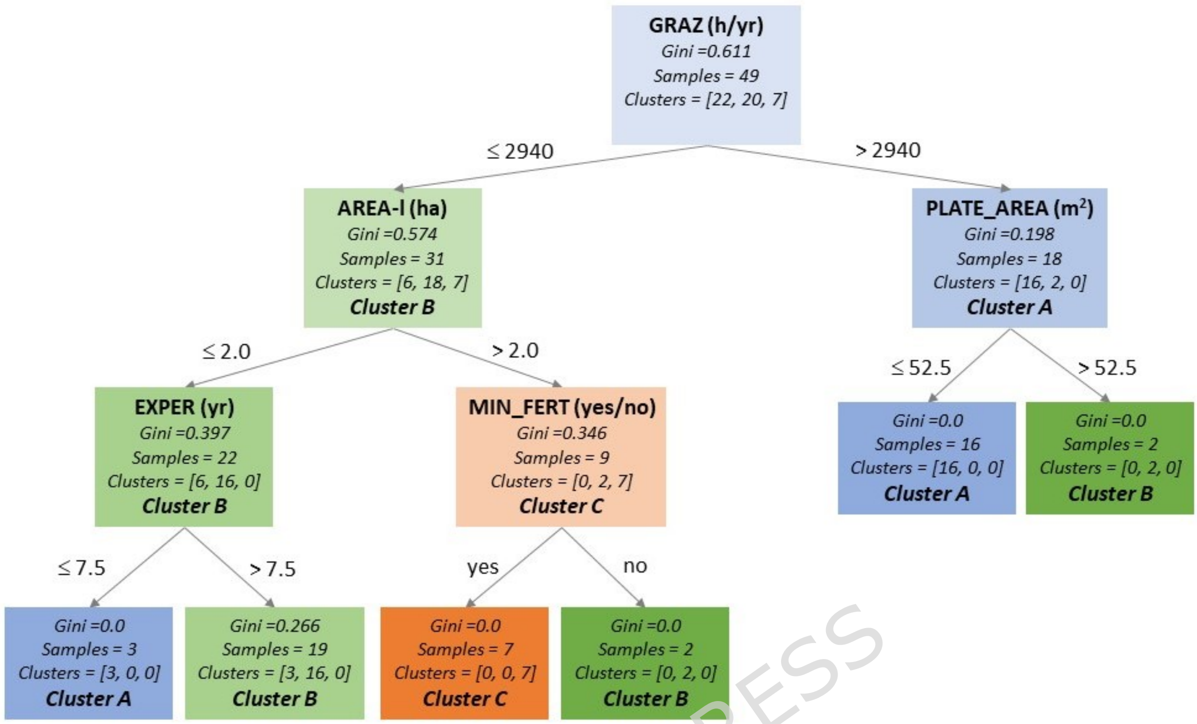

Fig. 5 Visual presentation of the most influential variables determining the types of small family-owned dairy farms based on decision tree classification model. For each branch, the color (orange, green, blue) corresponds to the dominant cluster found within that branch, whereas the saturation of that color is scaled by the branch's homogeneity (a higher proportion of samples from that single dominant cluster).

The most uniform path was determined for the least numerous groups of farms represented in Cluster C. Farmers which typically practised grazing for a shorter time (GRAZ < 2940 h yr^{-1}), leased at least 2 ha of arable land (AREA-l) and used mineral fertilisers on fields (MIN_FERT), very likely belonged to this cluster.

Similarly, the key characteristics of Cluster A were mainly defined by a long grazing period (GRAZ > 2940 h yr^{-1}) and a relatively small plate area for solid manure storage (PLATE_AREA < 52.5 m^2), which allowed the separation of more than 70% of farms belonging to the Cluster A within one single path. The rest (6 cases) followed the main path defining Cluster

B, where three farms were then separated from it by a feature that indicated low farmer experience in agriculture (EXPER < 7.5 yrs) and three others remained within this path.

Cluster B was the most heterogeneous group, determined by three decision paths that involved five key features. The dominant group of 16 farms (80% of cases), however, was typically defined also by grazing intensity (GRAZ) below 2940 h yr^{-1} as in Cluster C, but in the next step separated by the small, leased area (AREA-l) not exceeding 2 ha, and further by the larger farmers' experience (EXPER) exceeding 7.5 yrs in agriculture. A certain share of other farms (2 cases) also followed this path with respect to grazing and leased area, but then avoidance in utilization of mineral fertilisers (MIN_FERT >0.5) clearly separated them from the main group and classified closer to Cluster C. The remaining farms (2 cases), however, followed a completely different path, starting from the grazing period that exceeded the threshold defined for this class in the main branch. These farms were then defined by a large plate area for manure storage (PLATE_AREA) that exceeded 52.5 m^2, clearly separating them from the farms of Cluster A, which initially followed the same path.

Discussion

Heterogeneity of dairy farms from a regional perspective

In this study, we analysed the diversity and key profiles of small-scale farms carrying out dairy animals in Poland, focusing on two regions and the socioeconomic and management factors affecting their productivity and viability. A particular focus was placed on farms with a small number of dairy cows (1-5 dairy animals), as these contribute a wide range of socioeconomic and environmental benefits to society[43]. Our farm profiles were highly consistent with farm types identified at the European level[29]. Taking into account socioeconomic factors, smallholder farms from our study predominantly represented self-supply orientated types, categorized on European scale as "part-time" and "peasant" farms found in Poland, Romania, and Latvia[29]. On a regional scale, these types also corresponded to “two-occupational” and “hobby” farms identified in Central and Eastern parts of Poland[26]. In our study, these groups aligned closely with Cluster A and B, respectively. On the contrary, the farms within Cluster C, which were characterised by motivated owners with clear initiatives to grow and modernise their farms, could be classified as more forward-looking types, such as "new enterprise" according to international classification[29], and “professional farms”[26] or “developing farms”[25] based on national typology.

Considering factors closely related to dairy production, we could identify in our “part-time” group (Cluster A) some factors that indicated an approach to agriculture focused only on self-supply. The farmers kept a small land area and some animals, but without focussing on developing the farm in dairy production. There was no visible investment in infrastructure, such as buildings, sufficient space for animals, and manure storage facilities. Farmers did not invest in themselves by gaining knowledge in the production sector. Furthermore, this group was certainly unhappy with the financial results of dairy production, thus, focussing mostly on self-supply. The farmers from Cluster B (the “peasant” group) showed certain similarities with those in Cluster A, such as financial dissatisfaction, uncertainty about the future, and consideration of leaving the profession. However, unlike Cluster A, they had more experience in agriculture and slightly better infrastructure and higher milk production, which allowed them to sell their products on the market. They represented a more traditional approach to dairy production. For both clusters, however, all these factors indicated a low potential to continue in any direction and a high probability of stopping animal production in a short-term perspective, unlike other study predicted for Poland[25]. The medium or poor agricultural situation in the south-eastern Polish voivodeships helps partially explain this general picture[44,45]. Agriculture in these voivodeships exhibits the lowest levels of labour and capital productivity, the smallest capital-to-labour and land-to-labour ratios, and struggles with a problem related to agrarian fragmentation and adverse environmental conditions[20,45,46–]. Farmers from southern and eastern Poland are also less likely to use EU funds compared to areas with more developed agriculture, which further hampers potential investments[20]. Many struggle to meet the EU's stringent requirements, particularly in milk production and dairy products, where the standards are particularly demanding[34]. Some farmers purposefully opt for diversified agricultural activities rather than specialisation, as they see this as a practical and economically viable approach that aligns with their personal values. This strategy helps reduce their dependence on external resources while ensuring higher-quality food for their households[34]. Recent studies also show that, apart from strictly agricultural production factors, land can be a capital investment for its owners[26]. This phenomenon occurs due to the rising land prices, a factor that has largely been omitted, when considering the prospects of small farms.

In contrast, the farms within Cluster C stood out as the most promising type. Their owners demonstrated strong dedication to their profession, actively working to improve conditions and modernise operations. These farms typically had larger areas, which enabled stronger focus on crop cultivation. This was also evident in their well-equipped machinery and use of mineral fertilisers. However, in contrast to the farms investigated in another Polish small farm study[25], animal production was rather a secondary activity, while crops were prioritised, and thus explaining the different outcomes with respect to farm continuation. The farmers' survival strategy seemed to be diversifying agricultural production, with plant production as the main focus and milk production as an additional element, but still mostly market-oriented. The reliance on own resources and the market orientation of products have already been identified as significant factors commonly used by smallholder farmers to maintain the resilience of their farms[24,47]. Importantly, despite the small scale of milk production, animal welfare standards, such as outdoor grazing and sufficient animal area in barns, were generally maintained in these farms. This aligns with growing consumer demand for products from animals raised with high welfare standards, as demonstrated by de Graaf et al.[48]. This professional approach to farm management differentiates them from other groups, likely due to their higher education levels and suggests the potential for supporting these farmers through training activities[25], and also renders this cluster of farmers more receptive to environmental considerations. This is also shown by their practice of manure incorporation and the use of larger manure plates, both indications of their ability to manage environmental risks.

Key factors underlying variability in smallholder dairy farms

Our study identified that grazing time was the most relevant factor in differentiating farms, followed by the interaction between infrastructure (e.g.: manure plates), practices (e.g.: land lease, mineral fertiliser use), and the level of experience of the farmer. The results highlighted the role of the type of agricultural production in shaping the heterogeneity of the farm profiles. For dairy farms, this primarily reflected the importance of pasture-based livestock management. This finding aligns with the long tradition of grazing dairy cattle as a cornerstone of small-scale farming in Poland[49]. Notably, extended grazing times were indicative of traditional systems with limited infrastructure, such as small manure storage areas, which were predominantly associated with Cluster A (the “part-time” type). Farmers in this group probably relied on pasture feeding as a cost-effective way to supplement livestock diets while also conserving time[50]. This approach offers advantages in terms of environmental sustainability, as grazing is widely recommended by researchers for its role in preserving cultural landscapes and supporting biodiversity[50]. Thus, while these systems may appear less modernised, their alignment with sustainable agricultural practices underscores their value in preserving ecological balance and cultural heritage. This alignment can be seen as an advantage, enhancing their potential for organic production, which could lead to increased milk sales and, consequently, improved profitability, while the generally low production intensity would minimise environmental harm.

On the contrary, reduced grazing times, greater reliance on leased land, and increased use of mineral fertilisers were characteristic features determining Cluster C. The area of leased land was a key distinguishing factor for these farms, indicating a shift toward a more prominent role of leased land. This contrasts with the lower shares of leased land typically observed in small-scale, extensive dairy farms in Central and Eastern Europe[16] but is easily explained by the specific land situation in this region, which has historically had the lowest agricultural area per farm due to fragmentation[46,51]. Due to their more forward-looking attitude, the farmers in cluster C could potentially be more attracted to environmentally beneficial practices.

Interestingly, the most experienced group of farmers (Cluster B) in many respects had similar characteristics as Cluster A, but did not take advantage of allowing for long grazing times to keep efforts and economic expenditures in feed provision low. Instead, this group is characterised by the smallest milk yield. Moreover, despite of their long experience and hence closest need in finding a successor, these group has least plans in that regard - the prevalent "I don't know" response may be regarded as fatalistic. Out of the three clusters, these farmers may be less inclined to take environmental measures into account. It is probably that this group will stop active production in near future and will sell or lease the fields to bigger farmers.

In evaluating the key parameters that determine different farm profiles, the role of social factors should also be mentioned. Social factors, particularly age, length of experience, and education, play a critical role in the continuation of farming. Well-educated farmers with agricultural experience are more motivated to implement changes that improve production efficiency and economic resilience[25]. This pattern is clearly visible in the group of “professional farmers” (Cluster C) of this study. Less educated and experienced farmers often report lower satisfaction and view agriculture as unprofitable, increasing their willingness to change profession[19]. On the contrary, experienced farmers express concerns about the future of their farms and succession[52], as the results indicate in Cluster B. As farm work differs from other jobs, with seasonal demands and irregular hours, factors such as job satisfaction, income satisfaction, and willingness to change careers are closely linked and can also shape farmers' perspectives[53]. Farmers who value rural lifestyles and self-sufficiency often report higher job satisfaction, despite lower income.

Factors such as inheriting the profession, maintaining traditions, and producing quality goods contribute to this satisfaction. Younger farmers with limited experience and higher expectations for living standards are more likely to express a desire to leave farming when income is unsatisfactory. Meanwhile, farmers focused on self-sufficiency tend to accept lower income expectations, finding satisfaction in independence. The role of community involvement and participation in local organisations also strengthens farmers' sense of identity and purpose of farmers, further increasing their job satisfaction[19].

It is worth noting the role of women in Polish small-scale farms. The proportion of women participating in the interviews (37%) closely reflected the general national proportion for Poland (34%)[54]. Analysis of the farm clusters, however, revealed notable variations (though not statistically significant), with the highest female representation observed in the least modern farms (Cluster B; 45%) and the lowest representation in the modern farms (Cluster C; 14%). This could be attributed to several interacting factors common in small-scale or struggling agricultural groups. The combination of characteristics observed in Cluster B (most experienced group, high uncertainty of farm continuation, highest proportion of milk sales, estimation of milk production to be profitable although quantitatively with the lowest milk production per cow) can be interpreted through the lens of women's resourcefulness and strategic management in the face of resource constraints and uncertainty. On one hand, it gives rise to the association that women in Polish rural areas have historically acted as the "managers of poverty" and are often noted for their strong focus on the efficiency of resources[55]. On the other hand, the high women representation can be a consequence of men having already sought more stable, off-farm work, leaving women to become the primary operators by necessity, especially as the farms age and succession planning fails[54].

Our results show the need to further explore the role of women in small-scale farming to understand how they are helping farms stay successful and shaping the future of agriculture. Also, understanding these social dimensions is crucial to developing effective policies and support systems that address the unique needs of farm workers, ultimately leading to improved working conditions and farm productivity.

The latest evidence also points to the fact that growing rural populations, land subdivision, and limited off-farm employment opportunities force people to rely on increasingly smaller land partitions, especially in developed countries[56]. Additional factors such as the ageing farming population, the outmigration of young people from rural areas, and the lack of successors have already led to farm abandonment as older farmers retire[28]. Lastly, the impact of climate change is emerging as a significant risk factor for agricultural production, in general[24,57,58]. In the dairy production, negative effects are expected on grassland production, fodder quality, cow health, and overall productivity[59]. For dairy production systems, this includes modifications of farm management practices, improvements in animal housing, feeding systems, and targeted breeding strategies aimed at improving resilience to climate effects[59].

Finally, it is important to note that this study used a purposive sample of 50 small dairy farms—selected by number of animals and region—to gather detailed, face-to-face insights into farm management and daily practices. While this focused sample limits broad generalization, the findings provide useful context for understanding small-scale dairy operations and provide a foundation for further research across other regions and farm types. The results also show that, when developing farm typologies, socioeconomic factors should be considered alongside structural and managerial characteristics. Consistent with these findings, we acknowledge that social capital and community engagement are crucial for the viability of small-scale farms. Future studies could explore these aspects using participatory approaches or social network analysis. Furthermore, longitudinal studies are essential, as their integration other factors, such as detailed financial data and market monitoring, would bring more understanding about the dynamics of these farm types in changing socioeconomic conditions to help develop adequate strategies to support them.

Conclusions

Our study provided a detailed analysis of the diversity of smallholder farms with the example of south-eastern Poland, covering a very specific context of the husbandry of dairy animals in a regionally distinct farming type identified within Europe. The results allowed us to identify key farm profiles based on production management practices and their socioeconomic characteristics. The study underlined the importance of grazing and leased areas as a critical differentiator for agricultural profiles, with traditional systems supporting sustainability and biodiversity, but facing challenges in profitability. In addition, social factors, including specifically farmer experience, were highlighted as crucial to farming continuity and job satisfaction. Taking advantage of different perspectives and interests of smallholder farmers, as has been expressed in the three clusters proposed, may guide toward policies that allow for farming viability without jeopardising environmental perspectives.

If maintaining the social fabric of economically strongly disadvantaged small dairy farms is considered a priority, the findings of this study may provide indications on how to shape support policies, given the multitude of challenges that farmers in general are confronted with. Our results point out that the diversity of the farm profiles needs to be reflected in such policies. For “part-time” and “low-income” farms (Cluster A), key priorities could include aspects such as diversification and training programmes, and the promotion of environmentally friendly practices to enhance their resilience to economic and environmental challenges. For experienced “peasant” and “hobby” farmers (Cluster B), the focus could be on promoting access to local markets, facilitated by ecological farming practices and encouraging sustainable farming methods. The developing and professionalised farms (Cluster C) may be best suited to benefit from prioritizing investments in further infrastructure modernisation, support for technological innovation to improve their market access for better growth potential and competitiveness. Here, identifying the relevant typologies will be essential to develop adequate developing strategies.

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Conceptualisation: AR, XDdO, JFM, DAMR, MSK; formal analysis: XDdO investigation: MK; methodology: AR, XDdO, JFM, MK, DAMR, MSK; visualisation: AR; writing-original draft: AR, DAMR, MSK, JFM; writing-review & editing: AR, XDdO, DAMR, FD, JFM, MK, MSK, WW, BA; supervision: BA; funding acquisition: FD, BA

Data availability

The data supporting this study were submitted to the Institute of Environmental Engineering at the University of Zielona Góra. Further inquiries can be directed to the corresponding author.

Competing interest

The authors declare no competing interests.

Ethical approval

All research methods were carried out in accordance with relevant guidelines and regulations, including the Declaration of Helsinki and the American Sociological Association (ASA) Code of Ethics. All experimental protocols and study procedures were approved by the Committee for Ethics of Sociological Research at the University of Zielona Góra. Informed consent was obtained from all participants involved in the study, and all data was handled in compliance with the General Data Protection Regulation (GDPR).