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Typologies of South African small-scale farmers and their risk perceptions: an unsupervised machine learning approach

Sara Yazdan Bakhsh
Department of Agricultural Economics and Rural Development, University of Göttingen, Göttingen, Germany
Kingsley Ayisi
Risk and Vulnerability Center, University of Limpopo, Polokwane, South Africa
Reimund P. Rötter
Tropical Plant Production and Agricultural Systems Modelling (TROPAGS), University of Göttingen, Göttingen, Germany
Wayne Twine
School of Animal, Plant and Environmental Sciences, University of the Witwatersrand Johannesburg, Johannesburg, South Africa, and
Jan-Henning Feil
Department of Agriculture, University of Applied Sciences South Westphalia, Iserlohn, Germany

Abstract

Purpose – Small-scale farmers are highly heterogeneous with regard to their types of farming, levels of technology adoption, degree of commercialization and many other factors. Such heterogeneous types, respectively groups of small-scale farming systems require different forms of government interventions. This paper applies a machine learning approach to analyze the typologies of small-scale farmers in South Africa based on a wide range of objective variables regarding their personal, farm and context characteristics, which support an effective, target-group-specific design and communication of policies.

Design/methodology/approach – A cluster analysis is performed based on a comprehensive quantitative and qualitative survey among 212 small-scale farmers, which was conducted in 2019 in the Limpopo Province of South Africa. An unsupervised machine learning approach, namely Partitioning Around Medoids (PAM), is applied to the survey data. Subsequently, the farmers' risk perceptions between the different clusters are analyzed and compared.

Findings – According to the results of the cluster analysis, the small-scale farmers of the investigated sample can be grouped into four types: subsistence-oriented farmers, semi-subsistence livestock-oriented farmers, semi-subsistence crop-oriented farmers and market-oriented farmers. The subsequently analyzed risk perceptions and attitudes differ considerably between these types.

Originality/value – This is the first typologisation of small-scale farmers based on a comprehensive collection of quantitative and qualitative variables, which can all be considered in the analysis through the

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application of an unsupervised machine learning approach, namely PAM. Such typologisation is a pre-requisite for the design of more target-group-specific and suitable policy interventions.

Keywords Agricultural policy design, Farmer typology, Machine learning, Partitioning around medoids, Risk perception, Small-scale farming

Paper type Research paper

1. Introduction

In African countries, the agricultural sector is amongst the most important economic sectors that can play a critical role in contributing to the achievement of the Sustainable Development Goals (SDGs), such as reducing poverty and hunger, attaining food security, and sustaining natural resources (Kofi and Adams, 2020). In this regard, improving the management of existing agricultural systems and, through this, enhancing sustainable land use is a prerequisite to sustaining food supply for a rapidly increasing population in Sub-Saharan Africa.

The agricultural sector in South Africa (RSA) in particular is largely dualistic, consisting of a modern and capital-intensive but comparatively small group of large-scale commercial farmers, as well as a large group of poorly-developed and resource-limited small-scale farmers, predominantly living in the rural former Apartheid homeland areas (Aliber and Cousins, 2013; Gwebu and Matthews, 2018). According to the General Household Survey of 2019 in South Africa, there are approximately 2.3 million small-scale farmers compared to 40,122 large-scale farmers (Mathinya *et al.*, 2022; STATS SA (Statistics South Africa), 2020). These outnumbering small-scale farmers play a crucial role in developing rural economies by providing food for own consumption and a growing urbanized population, thus, improving rural livelihoods and, more generally, food security in rural areas. Often, these small-scale farmers are seen as the main drivers of achieving the SDG imperatives in RSA (e.g. Aliber and Cousins, 2013).

The dualistic characteristic of the agricultural sector in RSA has had adverse effect on the development of small-scale farmers (Tshuma, 2014). This is mainly due to the fact that, historically, policy emphasis has mainly been put on the development and support of the formal commercial agricultural sector rather than on the much larger group of small-scale farmers (Carelsen *et al.*, 2021; Tshuma, 2014). However, over the past two and a half decades, the support has shifted more and more toward the small-scale farming sector (Hendriks, 2014; Pienaar, 2013; Vink and Van Rooyen, 2009). In addition, many researchers, policymakers, and civil society organizations in RSA have tried to understand the challenges the small-scale farmers are facing and implement various strategies and policies to enhance the status of small-scale agricultural production.

Despite various national and provincial government support programs for small-scale farmers to enhance the agricultural sector in recent years (Cele and Wale, 2018; FAO, 2017a; Gwebu and Matthews, 2018), these farmers are still extremely vulnerable to multiple agricultural risks and perform below their potential production capacities. In addition, they are confronted with many constraints that result in low productivity and, hence, food supply (Hart and Aliber, n.d.; Tshuma, 2014). By looking at the literature, two main reasons for the policy ineffectiveness for supporting small-scale farming systems in RSA are discussed.

The first reason might lay in the undifferentiated view and treatment towards these groups of farmers, with little consideration of contextual factors that render and exacerbate the unevenness between them (Olofsson, 2019). However, this disregards the fact that most of the time small-scale farmers are highly heterogeneous, for instance regarding types of farming, levels of technology adoption and degree of commercialization (Carelsen *et al.*, 2021; Madry *et al.*, 2017). Therefore, stereotypes need to be deconstructed to allow for a more target-group-oriented policy design. These heterogeneous groups of small-scale farmers require different forms of government interventions depending on the objectives and characteristics of each group (Carelsen *et al.*, 2021). Consequently, to design accurate target-group-oriented policy measures, a crucial pre-requisite is to understand the structure of the addressed group of small-scale farmers comprehensively and objectively.

The second reason for ineffective support policies for small-scale farmers might lay in the fact that farmers' risk attitudes and perceptions are largely disregarded when it comes to policy design. Small-scale farmers in developing countries and particularly in RSA have constantly been confronted with different sources of risks such as production, market, financial, institutional or political, and human resource risks. Risk perception has been recognized as an important influence on small-scale farmers' performance and decision-making, such as the adoption of different types of practices and new technologies (Bidogeza *et al.*, 2009; Joffre *et al.*, 2019). Heterogeneous farmers have diverse perceptions of risks, depending on their main farming goal and their farming typologies. In order to design comprehensive and effective target-group-oriented policy measures with the desired implications in practice, it is essential to understand the risk perceptions of the various target groups. Many research publications point out the importance of risk perception and risk attitude for understanding farmers' individual risk behavior (Boholm, 1998; Dave *et al.*, 2010; Pennings and Garcia, 2001; Renn, 1998; Van Winsen *et al.*, 2016). Farmers' decision-making on selecting and applying the optimal risk management strategies, amongst other, result from the interplay of their individual risk attitudes and their perceptions regarding the sources of these risks (Bidogeza *et al.*, 2009; Meraner and Finger, 2019; Sulewski and Kłoczko-Gajewska, 2014). Therefore, understanding the farmeŕs risk behavior, i.e. risk attitude and subjective risk perception of the farmers, is a prerequisite for designing appropriate risk management strategies and, hence, respective policy support programs (Sulewski and Kłoczko-Gajewska, 2014).

Therefore, the purpose of this paper is to analyze typologies of small-scale farmers in RSA based on a wide range of objective variables regarding their personal, farm, and context characteristics, which support effective and target-group-specific design as well as communication of policies. For this, a cluster analysis is conducted based on a comprehensive survey among small-scale farmers from 2019 in the Limpopo Province. It comprises a wide range of quantitative and qualitative variables about their farms, management practices, and socio-demographic characteristics. For identifying different types of small-scale farmers from this complex data, an unsupervised machine learning approach, that is, Partitioning Around Medoids (PAM) is used. Following this, the risk attitudes and risk perceptions are compared between the identified farmer types for the first time.

This study contributes to the literature by analyzing typologies of small-scale farmers in southern Africa based on a wide range of variables regarding their socio-demographics, their farm structures and their resource management characteristics as well as by linking these typologies with the analysis of their respective risk perceptions. Our respective results could provide a reference for decision makers for a more need-based and target-oriented policy design and communication for small-scale farmers, which is especially important in southern Africa. From the results, policy implications are exemplarily derived regarding the topics of extension services, the adaptation of irrigation technologies and access to credit [1].

The remainder of the paper is organized as follows: Section 2 provides an overview of existing limited typologies of small-scale farmers and their shortcomings in RSA. Section 3 describes the data and methodology. Section 4 presents the descriptive statistics and the PAM clustering results. In Section 5, we compare the risk attitudes and risk perceptions of the selected groups, and in Section 6 the results are discussed in relation to policy design. Finally, conclusions are drawn in Section 7.

2. Typologies of small-scale farming systems in South Africa

The definition of smallholders or small-scale farmers varies internationally between countries and agro-ecological zones (Dixon *et al.*, 2004; Pienaar, 2013), as these farmers are heterogeneous and vary significantly depending on farm characteristics including socioeconomic characteristics, resource endowments and agro-ecological dimensions (FAO, 2017a). The existing literature on classifying small-scale farmers uses diverse conceptual approaches and methods, depending on the purpose of the analysis and the units of investigation (e.g. farm, farmer). Several criteria such as farm size, sources of farming capital and income, labor, market integration, and livelihood diversification can be considered for the classification (Olofsson, 2019). Recent literature revealed that farm size and the objective of production are the two predominant criteria to classify small-scale farmers, although the threshold measures vary across countries and regions (FAO, 2017a).

In South African policy and planning documents, there are several definitions and terminologies for small-scale farmers which are inconsistent and differ depending on the context. Table 1 provides a brief overview of relevant farmer typologies in research studies and policy documentations in South Africa to focus on policy implementations.

The South African Department of Agriculture (DAFF), which is mainly responsible for designing the legislation and policies for the agricultural sector at the national level (Carelsen *et al.*, 2021), in 2015 generally classified small-scale farmers into the three groups, that is, “Part-time subsistence farmers” for which agriculture contributes merely a small share of

Author/Policy reference	Identified typologies	Criteria
Department of Agriculture, Fisheries, and Forestry (DAFF, 2015)	Subsistence farmers; smallholder farmers; commercial farmers	land size and production orientation
Department of Agriculture, Fisheries, and Forestry (DAFF, 2013)	Part-time smallholder (agriculture contributes only small share of livelihood); middle of the spectrum smallholder (rely on agriculture as the main source of livelihood); commercial smallholders (not obliged to register for VAT or income tax)	Degree of commercialization, importance of agriculture in household’s livelihood, poverty level
Department of Rural Development and Land Reform (DRDLR, 2009)	Landless households; commercial-ready subsistence producers; expanding commercial smallholders; well-established black commercial farmers; financially capable, aspirant black commercial farmers	Land size, production orientation, assets
Aliber *et al.* (2009)	Subsistence; semi-subsistence; emerging commercial farmers (or semi-commercial farmers)	Labor, source of income
Cousins (2010)	Supplementary food producers; Allotment holding wage workers; Worker-peasants; Petty commodity producers; Small-scale capitalist farmers; Capitalists whose main income is not from farming	degree of agriculture contributes to social reproduction or expanded reproduction, degree of hired labor in the agricultural production process
Torero (2011)	Smallholder farmers including Rural world 1; Rural world 2; and Rural world 3	Market level
Carelsen *et al.* (2021) adapted from Western Cape Department of Agriculture (WCDoA)	Subsistence; smallholder; Commercial farmers	Taxation, production intent, access to resources, labor, and technology level

Source(s): Authors’ own creation/work

Table 1. Classifications of farmers in South Africa

their livelihood, “middle of the spectrum smallholders” who mainly rely on agriculture as their main source of livelihood, as well as “commercial smallholders” (DAFF, 2015). These typologies are mainly based on the farmers’ land size and their primary purpose of production. Looking at these typologies, smallholders were mainly referred to as the farm categories between the two extreme groups of subsistence and large-scale commercial farmers, although they were classified into two groups of subsistence and emerging smallholder farmers. In doing so, subsistence smallholder farmers were defined as the ones involved in agricultural production only for their own household consumption, while emerging farmers were also considered to be selling their products at a market.

The farm typology according to DRDLR (2009) again classified farmers in five different categories based on the land reform projects. In comparison to other policy documents, they considered more criteria such as farmers’ aspirations, capabilities and resources.

In addition to the definitions of small-scale farmers from the agricultural policy and planning documents, various researchers attempt to define the small-scale farmers in SA (Aliber *et al.*, 2009; Cousins, 2010; Torero, 2011) as well as provincially, for example for Western Cape (Carelsen *et al.*, 2021).

However, based on the literature we screened, none of the existing typologies consider socioeconomic characteristics, risk attitudes, and resource management for differentiating among small-scale farmer groups. The existing typologies of (small-scale) farmers are still somewhat vague and too broad to represent the main characteristics of different groups of farmers, in order to design respective need-based policies to improve their specific situations.

3. Data and methodology

In the following section, the study area and data collection will be presented. Afterward the methodology on the classification of small-scale farming systems and determination of the optimal number of clusters are introduced.

3.1 Data collection

The research was conducted in the Limpopo province of South Africa, located in the north-east of the country. Climate variability in this province is characterized by a long dry spell in winter season along with irregular rainfall patterns in the summer season (October–April), which are also influenced by the El Nino-induced drought event (Mosase and Ahiablame, 2018).

Limpopo is one of the least developed provinces in South Africa compounded by an acute population growth rate and poverty. With a population of 5.8 million people, Limpopo comprises around 10% of the total population of South Africa (STATS SA, 2016). A large share of the population (89%) live in rural areas and farming is their main occupation (Gyekye and Akinboade, 2003; LDARD, 2012). We selected five study areas from Limpopo Province based on their climatic aridity differences, demography and socioeconomic factors. The selected sites are located in rural areas: Mafarana, Gavaza, Ga-Selwana, Makushane, and Ndengeza (Figure 1). These are situated in the Mopani district of Limpopo province. Farming systems in the selected areas are mainly small-scale farmers with limited resource endowments.

A structured questionnaire was conducted between April and July 2019 after pretesting in selected villages to interview in person with the farm household heads or the persons responsible for farm management. The purpose of the survey was to collect information on socioeconomic, demographic, farm and household characteristic as well as information on resource endowment and agricultural activities during 2018–19 crop seasons. Moreover, the information regarding risk attitude and risk perception of different sources of risks were collected from each farmer.

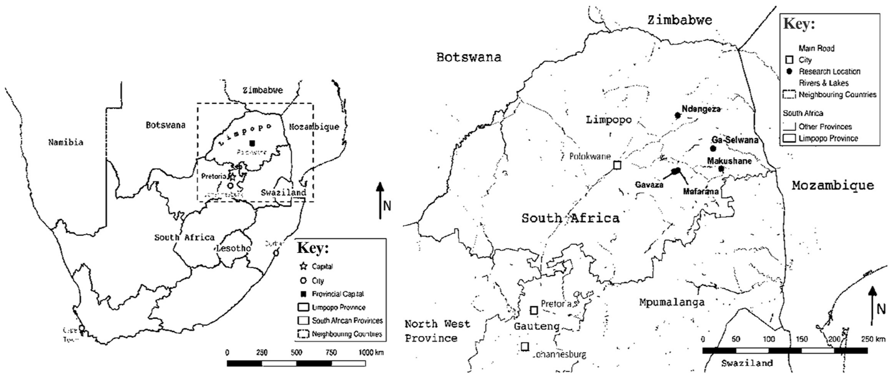

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Figure 1.
Research area map

Using a purposive random sampling procedure, data was collected from 215 smallholder farm households across the five selected villages in Limpopo, of which three had to be excluded due to incomplete information. Consequently, the final data set for the following analysis covered 212 observations. To capture the broadest possible diversity, the sample included different sized farms with diverse agricultural activities that had different degrees of market integration and self-provisioning, using snowball sampling in selected villages. Permission to access farmers was obtained from tribal authorities of each village.

3.2 Variables for classification

The diversity of small-scale farming systems in our study was determined by considering multidimensional criteria consisting of farmer characteristics (e.g. age, education, risk attitude, etc.), farm characteristics (e.g. agricultural production, agricultural income) and resource management characteristics (e.g. water sources and irrigation, labor, inputs), as well as external incentives (e.g. agricultural extension services, access to credits, and markets). In contrast to previous literature on small-scale farmer typologies, this vast and comprehensive accumulation of multidimensional variables provides a greater potential of an accurate determination of different farmer groups. These numerous variables used in the survey were based on an extensive upstream literature review as well as on numerous expert discussions prior to and during the design of the survey (cf. section 2). Table 2 presents the descriptive statistics of the selected continuous and categorical variables implemented in the clustering. A total of 34 variables were applied to construct the smallholder farming system classification.

According to this table, a typical farming household in the survey sample has a household head of an advanced age of about 66 years. The share of female-headed households in the survey is close to the one of the national general household survey in 2019 with 48.8% (Statistics South Africa, 2019). Risk attitude measured by farmers' is on average 4.29 and, with this, indicates slightly risk-averse within when it comes to farming.

The average farm in the survey owns 4.4 ha land, of which 70% is left fallow during winter (dry season). In terms of production systems, the smallholder farming system is mainly characterized by mixed crop-livestock production. Besides maize [2] (*Zea mays* L.), which is cultivated by almost all the farmers as the staple crop to ensure household food security, the secondary major crops are legumes [3] cultivated by 59% of farmers, fruits [4] with an average of 32%, and vegetables [5] with 15% of the farmers. Livestock consists of cattle, goats, pigs as well as chickens. Cattle provides the main source of livestock income.

Variables	Description	Mean	Std dev.	Min	Max
Farmer characteristics					
age	Age of household head (number of years)	66.45	11.19	33	93
gender	Gender of household head; (1 = Male)	0.52	0.50	0	1
educ	Years of formal education of household head	4.76	5.04	0	1
Job_offFarm	Off-farm job of the farmer; (1 = Yes)	0.22	0.41	0	1
Inc_socio	Social grant income including pension and child grant (in Rand)	26689.8	15308.7	0	69840
Inc_remit	Remittence income (in Rand)	4168.3	12026.5	0	96000
Risk_att	Risk attitude (Likert scale: 1: highly risk averse – 10: highly risk seeking	4.29	2.85	1	10
Farm characteristics					
Farm_area	Total area of the farm (ha)	4.44	6.13	0.25	47
Cult_area	Total area under cultivation (ha)	3.02	3.33	0	22
Winter_fallow_area	Share of fallow area in winter; between 0–1	0.70	0.43	0	1
Nr_winterCrops	Number of crops cultivated in winter	0.25	0.72	0	6
Cr_vegetables	Cultivating vegetables; (1 = Yes)	0.15	0.36	0	1
Cr_fruits	Cultivating fruits; (1 = Yes)	0.32	0.47	0	1
Cr_legumes	Cultivating legumes; (1 = Yes)	0.59	0.49	0	1
SaleValue_cropShare	Share of sale value crops to total value crops cultivated	0.40	0.41	0	1
SaleValue_animShare	Share of sale value animals to total value of animals	0.06	0.13	0	0.83
Animal	Having animal; (1 = Yes)	0.58	0.49	0	1
Nr_cattle	Number of cattle	4.6	9.4	0	65
Inc_onFarm	Income of selling crops and animals (Rand)	25137.9	121098	0	1574700
Inc_onFarm_crops	Crop share of total on-farm income	0.41	0.46	0	1
Inc_onFarm_anim	Animal share of total on-farm income	0.25	0.40	0	1
Resource management and external incentives					
OwnTractor	Having tractor; (1 = Yes)	0.06	0.23	0	1
Water source					
➢ Rain-dependent	Dummy; 1 = Yes, 0 = No	0.34	0.47	0	1
➢ Tap water	Dummy; 1 = Yes, 0 = No	0.41	0.49	0	1
➢ Public dam, lake	Dummy; 1 = Yes, 0 = No	0.09	0.29	0	1
➢ Private borehole	Dummy; 1 = Yes, 0 = No	0.16	0.36	0	1
Irrigation_Time	Hours of Irrigation in year	91.56	310.50	0	2184
Irrigation_Method	Methods of irrigation				
➢ No Irrigation	Dummy; 1 = Yes, 0 = No	0.34	0.47	0	1
➢ Primitive Irrigation method	Dummy; 1 = Yes, 0 = No	0.49	0.50	0	1
➢ Advances Irrigation method	Dummy; 1 = Yes, 0 = No	0.16	0.36	0	1
PesticideUse	Applying pesticide on farm; (1 = Yes)	0.14	0.34	0	1
FertilizerUse	Applying fertilizer on farm; (1 = Yes)	0.31	0.46	0	1

(*continued*)

Table 2.
Descriptive statistics of the variables

Variables	Description	Mean	Std dev.	Min	Max
Employee_Permanent	Number of hired permanent worker in year (Man-day)	48.50	255.60	0	2484
Employee_Seasonal	Number of hired seasonal worker in year (Man-day)	17.33	59.36	0	540
OnFarmMarket	Selling at farm; (1 = Yes)	0.58	0.49	0	1
OffFarmMarket	Selling at market; (1 = Yes)	0.17	0.38	0	1
CreditAccess	Access to credits; (1 = Yes)	0.10	0.30	0	1
Invest_past5Yrs	Investment in the past 5 years; (1 = Yes)	0.37	0.48	0	1
ExtVisits_Yr	Number of visits/support of Extension services	1.32	4.35	0	52

Source(s): Authors' own creation/work

Table 2.

On average, 41% of farm income is from crop sales and 25% is from livestock sales. Around 58% of the farmers sale their agricultural produce at their farm and 17% sale at off-farm markets such as retailers, fresh produce markets and livestock auction.

Social grants including old age- and child-support-grants play an important role on farm household incomes for most smallholders. According to Statistics South Africa (2019), around 59% of the households received grants as their main source of income in Limpopo. Direct agricultural support from government or extension services are mainly in the form of input supplies, mechanization, livestock health services, and providing information and training on farming practices. In SA, extension services are provided by the Department of Agricultural and Rural Development of the Province through their trained staff. They play an essential role in supporting small-scale farmers in the country and are therefore noted in various studies as one of the main influences on farm performance (Dube and Guveya, 2016; Magingxa *et al.*, 2009). We considered the number of visits of the agricultural extension officer during the previous year. In our sample, around 53.3% of the farmers received support from the local extension agents, with an average 1.32 visits in a year. Access to credit from formal financial institutions is a significant limitation for the majority of the South African small-scale farmers who are mostly old aged and have mainly unreliable and low income, undocumented property, and no formal credit history (Myeni *et al.*, 2019; von Loeper *et al.*, 2016). Within our sample, only 10% of the respondents have access to formal credit, although 37% of the farmers invested in the last five years, mainly on equipment for irrigation, fences, and machinery. Besides household members as labor on farm, the permanently and seasonally employed labor worked on average 48.5 and 17.33 man-days per year (eight-hour labor days).

The most common source of water is tap water (41%) which is usually only available in the home garden next to their residential building. 34% of the sample is purely rain-dependent, while on average 9 and 16% of farmers have access to public water sources and private boreholes. Hence, 49% of the sample uses primitive irrigation methods (e.g. buckets, farrow).

3.3 Clustering methodology

Clustering belongs to the unsupervised learning techniques and allows to identify patterns within the data at hand to create homogenous groups by considering the similarities of members within a group and dissimilarities between the groups (Graskemper *et al.*, 2021; Morris *et al.*, 2017).

In general, clustering methods are distinguished into hierarchical and non-hierarchical (partitioning) based approaches. One of the most popular clustering methods based on partitioning is the k-mean algorithm (MacQueen, 1967) which applies only for continuous quantitative data types. Conversely, Partitioning around medoids (PAM) (Kaufman and Rousseeuw, 1990) is an appropriate method in analyzing mixed-type data, considering both quantitative and qualitative (e.g. nominal, ordinal, and interval) data (Graskemper *et al.*, 2021; Lesmeister, 2015). The partitioning methods rely mainly on the initial center of the cluster (Xu and Tian, 2015). Accordingly, k-means consider the mean of the data sets as the center of the cluster, whereas k-medoids consider the median for the selection center of the cluster. Therefore, k-medoids are generally more robust against noise and outliers in comparison to k-means (Xu and Tian, 2015).

Partitioning around medoids (PAM) is one of the popular methods of k-medoids algorithm (Arunachalam and Kumar, 2018). The appropriate distance metric for PAM clustering which is suitable for mixed data type is Gower dissimilarity matrix (Guarín *et al.*, 2020; Weltin *et al.*, 2017). According to Gower (1971), the dissimilarity measure for a pair of observations (i and j) is defined as a weighted sum of dissimilarities for each variable as follows:

$$d(x_{ik}, x_{jk}) = \frac{\sum_k \delta_{ijk} d_{ijk}}{\sum_k \delta_{ijk}} \tag{1}$$

where d_{ijk} represents the distance between the ith and jth observation considering the kth variable and depends on the type of variables. For discrete variables (e.g. binary variables, categorical nominal variables), it is obtained as: $d_{ijk} = 0$ if $x_{ik} = x_{jk}$, and 1 otherwise. As well for the continuous variables:

$$d_{ijk} = \frac{|x_{ik} - x_{jk}|}{R_k} \tag{2}$$

Being the R_k is the range of the kth variable. Moreover, for categorical ordinal variables, the corresponding position index r_{ik} in the factor levels are transformed as follows to z_{ik} and treated as numerical variables:

$$z_{ik} = \frac{(r_{ik} - 1)}{max(r_{ik}) - 1} \tag{3}$$

The δ_{ijk} is a 0–1 coefficient based on whether the variables are valid (= 1) or else (= 0).

The Gower dissimilarity matrix is used as an input for the clustering procedure with PAM, with the main objective of minimize the sum of dissimilarities between all observations and the nearest medoid (Lesmeister, 2015). The analysis was conducted using R statistics software and the Gower dissimilarity matrix was computed using “dist” or “daisy” functions from the “cluster” package (Arunachalam and Kumar, 2018).

3.4 Optimal number of clusters

The selection of an optimal number of clusters is the prerequisite for clustering (Lesmeister, 2015). To determine the optimal number of clusters, the Silhouette index or Average Silhouette Width approach is conducted. This method tries to compare the similarity of observations within their assigned cluster to the similarity to all other clusters and measures the quality of the clustering. Based on this method, a high average silhouette width indicates good clustering. The optimal number of clusters (k) is the one that maximizes the average silhouette over a range of possible values for K (Kaufman and Rousseeuw, 1990).

According to Figure 2, the appropriate number of clusters is four based on the highest value of silhouette width. In addition, the Elbow method using the within-cluster sum of squares confirmed the optimal number of four clusters for the small-scale farming systems in South Africa (Appendix).

As a final step of the analysis, the nonparametric test of Kruskal–Wallis was conducted to evaluate whether there were significant differences in the distributions of the variables across different clusters of farmers. This test is an appropriate approach for mixed-type variables, with a chi-square distribution.

4. Results

In the following, the PAM clustering analysis is conducted and the resulting clusters of small-scale farmers are compared with regard to their characteristics.

4.1 Defining the clusters

Using the k-medoids clustering method, 212 smallholder farm households were grouped into four clusters of 80, 48, 54, and 30 members. These four groups were specified based on their main criteria of purpose of farming, agricultural activities and resource management. The largest cluster with 37.7% of the farmers represents the group of *Subsistence oriented farmers*, while the smallest cluster with 14% of respondents indicates the *commercial (market)-oriented farmers*. The other two clusters are the *Semi-subsistence livestock farmers* as well as the *crop-oriented farmers* that predominantly produce for their own consumption and sell their surplus at their farm. This means that the latter two groups can be understood as intermediate groups in their development.

4.2 Characterization and comparison of the clusters

Table 3 describes the results of each cluster in terms of various characteristics of the farmers which develop the profile of each group. These profile variables relate to farmer, farm, and resource management characteristics. The table presents the mean and standard deviations for continuous variables and the distribution proportion (percentage) for categorical variables for each of the farmer type clusters. The last column shows the results of the Kruskal–Wallis test to evaluate the performance of the variables in the different clusters to be significantly different from each other (p-value).

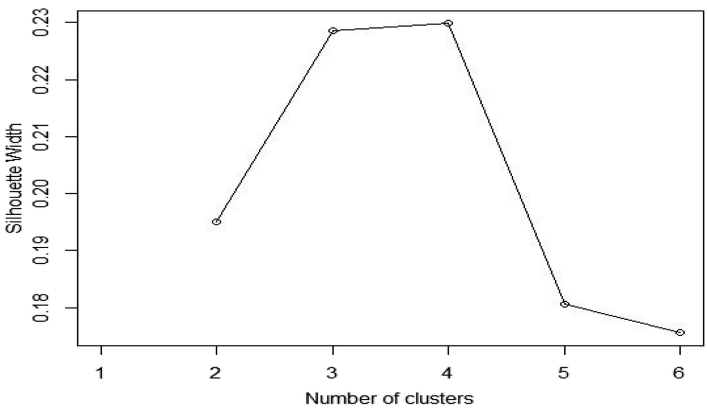

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Figure 2. Optimal number of clusters based on average Silhouette method

Clusters Number of members	Subsistence oriented 80	Semi-subsistence livestock-oriented 48	Semi-subsistence crop-oriented 54	Market-oriented 30	Overall significance (Kruskal–Wallis test)
Farm characteristics					
Age	70.7 (10.6)	65.9 (10.7)	64.5 (7.95)	59.6 (14.1)	0.000
Gender	0.35	0.77	0.31	0.93	0.000
Educ	2.62 (3.58)	5.6 (4.82)	4.50 (4.71)	9.60 (5.80)	0.000
Job_offFarm	0.24	0.19	0.15	0.34	0.229
Inc_socio	26676 (12391)	31670 (18081)	25080 (13421)	21656 (18861)	0.026
Inc_remit	5487 (13471)	4350 (14991)	3080 (7439)	2320 (9057)	0.215
Risk_att	3.5	4.6	4.1	6.10	0.000
Farmer characteristics					
Farm_area	2.93(2.41)	4.59 (6.20)	2.83 (2.13)	11.1 (11.4)	0.000
Cult_area	2.34 (1.87)	2.83 (3.16)	2.42 (2.06)	6.23 (5.88)	0.009
Winter_fallow_area	0.85 (0.34)	0.63 (0.46)	0.80 (0.38)	0.29(0.39)	0.000
Nr_winterCrops	0.06 (0.37)	0.19 (0.89)	0.07 (0.26)	1.20 (0.96)	0.000
Cr_vegetables	0.01	0.08	0.06	0.80	0.000
Cr_fruits	0.01	0.52	0.72	0.10	0.000
Cr_legumes	0.85	0.33	0.65	0.23	0.000
SaleValue_cropShare	0.05 (0.20)	0.35 (0.38)	0.66 (0.25)	0.91 (0.15)	0.000
SaleValue_animShare	0.01 (0.04)	0.14 (0.12)	0.02 (0.06)	0.15 (0.25)	0.000
Animal	0.44	1.00	0.43	0.60	0.000
Nr_cattle	3.22 (8.97)	8.56 (10.8)	1.41 (3.27)	7.83 (12.5)	0.000
Inc_onFarm	1740 (6335)	13504 (21033)	2860 (4548)	146121 (296717)	0.000
Inc_onFarm_crops	0.03 (0.16)	0.22 (0.35)	0.96 (0.16)	0.77 (0.32)	0.000
Inc_onFarm_anim	0.11 (0.30)	0.68 (0.41)	0.04 (0.16)	0.23 (0.32)	0.000
Resource management and external incentives					
OwnTractor	0.02	0.00	0.02	0.30	0.000
Water source					0.000
• Rain-dependent	0.58	0.27	0.22	0.03	
• Tap water	0.33	0.52	0.61	0.10	
• Public dam, lake	0.03	0.08	0.06	0.37	
• Private borehole	0.07	0.12	0.11	0.50	
Irrigation_Time	0.00 (0.00)	0.00 (0.00)	3.85 (28.3)	640 (581)	
Irrigation_Method					0.000
• No Irrigation	1.00	1.00	0.98	0.20	
• Primitive Irrigation method	0.00	0.00	0.02	0.07	

Table 3.
Results of cluster analysis

(*continued*)

Clusters Number of members	Subsistence oriented 80	Semi-subsistence livestock-oriented 48	Semi-subsistence crop-oriented 54	Market-oriented 30	Overall significance (Kruskal–Wallis test)
• Advances Irrigation method	0.00	0.00	0.00	0.73	
PesticideUse	0.05	0.08	0.04	0.63	0.000
FertilizerUse	0.30	0.23	0.20	0.67	0.000
Employee_Permanent	5.82 (36.8)	2.58 (16.6)	0.00 (0.00)	323 (617)	0.000
Employee_Seasonal	9.19 (21.2)	8.48 (18.8)	9.44 (24.4)	67.3 (140)	0.505
OnFarmMarket	0.09	0.94	0.96	0.67	0.000
OffFarmMarket	0.00	0.10	0.09	0.90	0.000
CreditAccess	0.02	0.06	0.06	0.43	0.000
Invest_past5Yrs	0.19	0.27	0.48	0.83	0.000
ExtVisits_Yr	0.78 (1.45)	0.48 (0.68)	0.54 (0.54)	5.50 (10.5)	0.000

Note(s): *numbers in ( ) is the standard deviations for the numerical variables
Source(s): Authors' own creation/work

Table 3.

Additionally, Figure 3 illustrates the relative distribution of the variables' expression for the selected four groups. In order to check the robustness of the clusters, we also employed K-mean clustering approach with the Elbow method of determining the number of clusters. The context and definitions of the clusters were confirmed the optimal number of four clusters for the small-scale farming systems in South Africa, similar to PAM results. The Elbow figure and K-mean results are in the Appendix section.

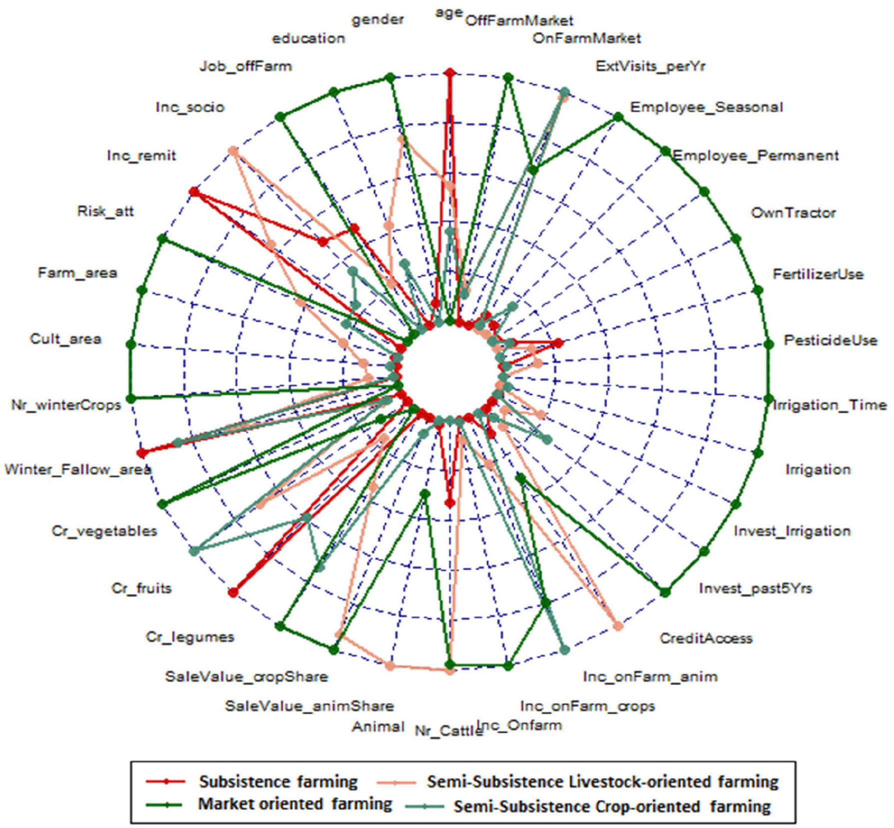
4.3 Farmer characteristics

The four defined clusters are diverse in terms of the characteristics of the farmers. As shown in Figure 3, Subsistence-oriented farmers are mainly women with an average age of 71 years old. They are mainly illiterate with an average of 3 years of formal education. Their main sources of income are remittances and social grants (mainly pension). In contrast, a market-oriented farming system is characterized by predominantly male farmers with higher education in comparison to other groups. The share of social grants and remittances are lower in comparison to other groups, as they are comparatively younger and more involved in off-farm jobs.

In terms of perceived risk attitude, subsistence-oriented farmers and semi-subsistence crop-oriented farmers are more risk averse, whereas market-oriented farmers and semi-subsistence livestock-oriented farmers take more risks.

4.4 Farm characteristics

Subsistence and semi-subsistence crop-oriented farming have the least land area which is mainly cultivated in summer (wet season) and are almost fallow in dry seasons. Their main focus of cultivation is staple food and legumes for own household consumption. Market-oriented farmers have access to bigger land areas with cultivating in both seasons. They are involved in agricultural diversification with the focus mostly on vegetables and livestock. Their main purpose of cultivation is for marketing.



Source(s): Authors' own creation/work

Figure 3.
PAM results: Characteristics of different farmer groups. Relative distribution of the expression of the variables

Semi-subsistence livestock-oriented farmers have the second highest land area but in terms of cultivation are mainly fallow. Their focus is mainly on livestock (predominantly cattle) with a higher share of farming income. Regarding cultivation, fruits and legumes are their second interests.

4.5 Resource management characteristics

Taking a closer look at each farming systems regarding resource endowments, market-oriented farmers are comparably more developed than the other groups. Most of the farmers in this group have access to private boreholes and irrigate their farms with drippers and sprinklers. A high share of farmers in this group apply fertilizer and pesticides on their fields and employ permanent and seasonal laborers. These farmers have access to markets where they can sell most of their products.

With regard to finance access and investment, market-oriented farmers have more possibility to get agricultural credits which results in more investment in the agricultural sector. The other three types of farmers are constrained by financial access, which also affects providing agricultural inputs such as pesticide, fertilizer, water source and hired labor.

5. Diversity of risk attitudes and perceptions between small-scale farmers' groups

Farming is inherently a risky business, especially for the small-scale farmers in developing countries like RSA with limited sources of endowments. Farmers are confronted with risks and uncertainties arising from a wide range of sources such as climatic, production, financial and market risks in agricultural production. How farmers respond to these risks and implement appropriate risk management practices and strategies is complex and varies among farmers depending on the individual's assessment of the risk involved (Boholm, 1998; Dave *et al.*, 2010; Pennings and Garcia, 2001; Renn, 1998; Van Winsen *et al.*, 2016). Therefore, understanding the farmer's risk attitude and subjective risk perception of the farmers is a prerequisite in policy implications on formulating appropriate risk management strategies (Sulewski and Kłoczko-Gajewska, 2014).

Risk attitude explains the farmers' self-assessment regarding risk-taking behavior and it can vary from unwilling to take risk to highly willing to take risk (Van Winsen *et al.*, 2016). In this regard, the farmers were asked about their willingness to take or avoid risks in making decisions for their farm, scoring on a Likert scale from 1 (highly risk averse) to 10 (highly risk taking). Based on the results, the subsistence small-scale farmers are more risk-averse, while market-oriented small-scale farmers tend to take more risks in their farming (Table 4).

According to previous studies (Flaten *et al.*, 2005; Meraner and Finger, 2019; Meuwissen *et al.*, 2001; Van Winsen *et al.*, 2016), risk perception can be considered as the combination of the probability of the occurrence of the risk (uncertain event) and the potential negative consequence of that. In this regard, to investigate the farmers' subjective risk perception, a total of 15 main risk sources, which are grouped into five main risk categories (Patrick and Musser, 2002) were asked from the small-scale farmers in the selected villages. The main sources of risks were collected from the previous literature (Duong *et al.*, 2019; Meraner and Finger, 2019; Van Winsen *et al.*, 2016), as well as interviews with some farmers and extension service consultants during pretesting of the main survey. Farmers were asked to score the perceived likelihood of occurrence on a five-point Likert scale, from 1 (very unlikely) to 5 (very likely) and the perceived impact (potential damage) from 1 (very low) to 5 (very high) for each selected risk. The perceived risk perception score is calculated by multiplying the two perceived scores for each of the risk sources. Moreover, by taking the mean overall risk scores in each category, we obtained the risk score for each category. Table 4 shows the results of the risk attitude and perceived likelihood of the risk sources, perceived impact of the risk and the perceived risk score in the four different types of small-scale farmers.

The results for the perceived likelihood of risk sources indicate that the first five main risk sources for these four groups are as follows:

Subsistence oriented farmers: 1. Drought, 2. Pests and disease, 3. Sudden lack of money for basic requirement, 4. Uncertainty of receiving credits, and 5. Reduced land availability

Semi-subsistence crop-oriented farming: 1. Drought, 2. Pests and disease, 3. Sudden lack of money for basic requirement, 4. Uncertainty of receiving credits and 5. Theft (crops)

Semi-subsistence livestock-oriented farming: 1. Drought, 2. Pests and disease, 3. Theft (livestock), 4. Sudden lack of money for basic requirement and 5. Lack of feed and fodder supply

Market oriented farmers: 1. Price volatility on sales markets, 2. Drought, 3. Pests and disease, 4. Uncertainty of receiving credits, 5. Limited availability of qualified (skilled) workforce

Table 4.
Risk attitudes and risk perceptions

Cluster Names	Subsistence oriented			Semi-subsistence livestock-oriented			Semi-subsistence crop-oriented			Market-oriented		
Number of members	80			48			54			30		
Risk attitude	*3.5*			*4.6*			*4.1*			*6.10*		
	prob[a]	imp[b]	score	prob[a]	imp[b]	score	prob[a]	imp[b]	score	prob[a]	imp[b]	score
Climatic/ weather risks	2.70	3.46	*10.55*	2.49	3.42	*9.41*	2.59	3.52	*10.18*	2.40	2.47	*6.92*
Drought	3.94	4.64	*18.36*	3.77	4.44	*16.98*	3.80	4.67	*17.93*	3.63	3.40	*13.00*
Flooding	1.98	2.85	*6.11*	1.65	3.13	*5.38*	1.87	3.06	*6.13*	1.67	2.40	*4.43*
Storm/wind	2.20	2.89	*7.18*	2.06	2.69	*5.88*	2.09	2.83	*6.48*	1.90	1.60	*3.33*
Production risks	2.41	2.64	*7.76*	2.66	2.48	*7.86*	2.31	2.24	*6.63*	2.40	2.20	*6.66*
Pests or diseases	4.18	4.10	*17.59*	3.85	3.77	*14.96*	4.11	4.00	*16.93*	3.83	3.07	*12.40*
Epidemic animal diseases	2.19	2.34	*6.39*	2.29	2.48	*6.48*	1.83	1.69	*3.57*	2.07	1.67	*3.83*
Lack of feed and fodder supply	2.64	2.29	*7.16*	2.85	2.54	*7.98*	1.78	1.85	*4.59*	2.20	1.87	*5.13*
Reduced land availability	2.33	3.26	*7.59*	2.63	1.85	*5.96*	2.63	2.24	*6.24*	2.43	2.27	*7.80*
Theft (crops)	2.24	2.61	*6.94*	2.65	2.13	*6.02*	2.80	2.46	*7.80*	2.20	1.80	*4.97*
Theft (livestock)	1.95	2.49	*6.19*	3.00	3.15	*11.02*	1.76	1.94	*4.76*	1.90	2.07	*5.47*
Theft (equipment)	1.33	1.38	*2.50*	1.33	1.44	*2.60*	1.24	1.50	*2.50*	2.13	2.63	*7.00*
Market and price risks	1.52	1.74	*3.01*	1.96	2.11	*4.65*	1.86	2.06	*4.20*	3.38	2.82	*10.77*
Price volatility on sales markets	1.43	1.24	*2.14*	2.19	2.38	*5.79*	2.07	2.13	*4.94*	4.10	3.57	*15.07*
Price volatility on purchase markets/ inputs	1.61	2.25	*3.89*	1.73	1.85	*3.50*	1.65	2.00	*3.46*	2.67	2.07	*6.47*
Financial risks	3.83	2.82	*10.03*	3.67	2.41	*8.50*	3.67	2.56	*8.81*	2.67	2.53	*7.18*
Sudden lack of money for basic requirement	2.78	3.86	*11.46*	2.60	3.08	*9.04*	2.65	3.41	*9.65*	1.87	2.10	*4.50*
Uncertainty of receiving credits	4.88	1.79	*8.60*	4.73	1.73	*7.96*	4.69	1.72	*7.96*	3.47	2.97	*9.87*
Other risks												
Limited availability of qualified (skilled) workforce	1.68	1.95	*3.68*	2.06	1.83	*4.42*	2.30	2.25	*5.72*	2.83	2.97	*8.70*

Note(s): a. Perceived (probability) likelihood of occurrence of the risk; b. Perceived impact (potential damage) of the risk

6. Discussion and policy implications

The results of the clustering analysis indicate that small-scale farmers in Limpopo can be classified into four groups based on their farmer, farm and resource management characteristics. In contrast to the previous agricultural policy documentation in RSA, which grouped small-scale farmers merely into two groups of subsistence farmers on one hand and market-oriented farmers on the other hand (Aliber *et al.*, 2009; DAFF, 2012; Pienaar, 2013), the endogenous result of the present cluster analysis based on PAM and a wide range of variables provides a more comprehensive classification, including livestock and crop oriented semi-subsistence farming.

Based on these results, the group of subsistence farmers has a relatively high proportion of members and consists of farmers who practice farming mainly to provide staple foods for their own household consumption. They prefer to grow mainly legumes on rain-fed land, with low access to inputs and finance. Their primary sources of income are from social grants (including child and pension), borrowing money (and remittance), and off-farm jobs (e.g. working as a daily wage laborer). These farmers are highly dependent on government and extension service support to meet household food security. These farmers are mainly risk averse when applying the least technology and strategy management on their farm. Therefore, they are more vulnerable to drought and pest risks in comparison to other groups of farmers.

Market-oriented farmers have sufficient land and labor resources, as well as access to water and other inputs to diversify production, mainly aiming for selling at markets. They grow vegetables predominantly. Their primary sources of income are selling agricultural products and other off-farm jobs. Hence, comparatively, financial capital is not a constraint for them and some of them have already invested in more advanced irrigation equipment. These farmers are the risk-taking groups of farmers and adopt more technologies at their farm. Nevertheless, they perceived the price fluctuations for the agricultural products as their main source of risk.

The semi-subsistence crop- as well as livestock-oriented farmers, which can be seen as intermediate groups between the former mentioned groups, have farming as the core activity that supports their livelihood and income. Farmers in the crop-oriented group grow diverse crops such as fruits and legumes and some vegetables for their self-consumption and sell their surplus at the farm gate. The livestock-oriented farmers keep mainly cattle, goats, and sheep and grow some fruits. These farmers are a rather risk-averse groups of farmers.

According to the literature, heterogeneous groups of small-scale faming systems require different forms of government interventions, depending on their respective characteristics. Based on our four identified farmer typologies, we discuss the respective implications for a need-based policy design at the example of three potential interventions, which are often discussed:

Extension services support: The results indicated that access to extension services and distribution of their support among different farm-types of small-scale farmers are not the same and skewed to particular farming groups, especially market-oriented farmers (Table 3). Previous studies indicated the low ratio of extension officers to farmers, poor quality of formal education, and lack of appropriate practical training as the main constraints to extension services (Aliber *et al.*, 2009; Dunjana *et al.*, 2018). Improving the effectiveness of extension support can be reached by providing various forms of support to specific farm types by designated skilled extension officers (Aliber *et al.*, 2009). Subsistence farmers can get support (e.g. technical support, initial provision of inputs, capacity building and motivation (Aliber *et al.*, 2009)) with the aim of increasing livelihood sources and to improve food security (Pienaar, 2013). The support related to semi-structured crop (/livestock)-oriented farming systems should be aimed at involving specialized crop (/livestock) species, production diversification and transfer information. Moreover, market-oriented farmers require knowledgeable extension officers regarding crop-livestock diversification systems with advanced technologies, with the goal of increasing productivity and market accessibility. Hence, extension services should be structured in a differentiated way with respective experts focusing on specific farm types rather than merely offering a "one-for-all" solution.

Water supply and irrigation schemes: Sub-Saharan Africa is exposed to severe drought conditions in recent years, which are exacerbated after the El Nino event during the 2015/16 cropping season (Hove and Kambanje, 2019). The drought-induced condition, which is attributed to prolonged dry periods and irregular precipitation patterns, poses high risks to agricultural production (Setimela *et al.*, 2018). Access to water and irrigation technology play an important role in the further development of small-scale farming systems. However, the share of irrigated land for these farmers is still very small compared to the country's overall farmland. It is crucial to create conditions to build and develop water supply and irrigation infrastructure based on the specific characteristics of the respective farm target group. For instance, household-based rainwater harvesting techniques can be an appropriate and affordable way to access irrigation water for subsistence-oriented farmers, while more advanced and capital intensive irrigation technologies might be better suited for market-oriented farmers with a higher farm size and income potential (Baiphethi and Jacobs, 2009). Therefore, the design and communication respective support policies should incorporate such different farm characteristics.

Credits and financial support: Limited access to credits is one of the major constraints of small-scale farmers in Southern Africa in adopting agricultural technologies and making agricultural financial decisions. Previous studies investigated the principal factors of agricultural credit constraints from two aspects of supply and demand. Accordingly, limited availability of credit sources and high costs of borrowing are the main constraints to the supply-side factors. However, risk-averse attitude and financial illiteracy of borrowers, as well as high transaction costs are the main constraints on the demand-side (Balana *et al.*, 2020). Improving credit access requires considering these two factors. The main funding institutions for the agricultural sector in South Africa are the Comprehensive Agricultural Support Program (CASP) and Micro-agricultural Financial Institutions of South Africa (Mafisa) (DAFF, 2015). Their main focus currently is to support market-oriented farmers who have some property rights and income to adopt new technologies. Subsistence-oriented farmers, however, often merely hold a communal land title, a so-called Permission to Occupy (PTO), which in conjunction with their lack of capital assets are not considered as collateral by financial institutions. Thus, politicians should incorporate those different farm groups and characteristics when designing target-based credit access through their financial institutions. For instance, for subsistence-oriented farmers credits with rather limited scope on one hand but lower collateral requirements on the other hand might be more effective.

7. Concluding remarks

To design and implement support policies for small-scale farmers need-based and target-group specific, it is a prerequisite to understand the structure of the farmers in a comprehensive way by considering a wide range of variables. In this regard, the purpose of the paper was to develop the typology of the smallholder farmers in the Limpopo province of South Africa. Farm level survey data from 212 smallholder farmers in five selected regions of Limpopo was collected in 2019 and analyzed by using the PAM clustering method. According to the results, the smallholder farmers in the sample can be classified into four different groups: subsistence-oriented (N = 80), semi-subsistence-livestock oriented (N = 48), semi-subsistence-crop oriented (N = 54) and market-oriented farmers (N = 30). The key factors in the farming system diversity was the farmer characteristics such as education and risk attitude, farm performance such as agricultural production, diversification, market oriented, as well as access to finance.

The classification of small-scale farming systems and the main drivers of diversity provide an entry point for a more need-based and, thus, more effective design and communication of respective support policies. Irrespective whether such intended support policies are supposed to concentrate merely on specific issues or on wider playing fields, it is important that an upstream classification of farmers supporting this is conducted based on multidimensional data. For instance, for designing and communicating water and irrigation policies, it is important to consider many aspects regarding the specific structures of farms, their household composition and income, their access to capital and their education and training. Moreover, agricultural development policy in RSA in general has widely concentrates on commercially oriented small-scale farmers rather than subsistence farmers. Our results indicate that the share of subsistence and semi-subsistence farmers are high in comparison to market-oriented farmers and, therefore, require more attention and support from politicians in comparison. In addition, knowledge of farmers' risk attitudes and perceptions of different sources of risks is a prerequisite for designing and communicating policies to support effective agricultural risk management for different types of small-scale farmers. For instance, relatively risk-averse farmers might be more receptive towards policy interventions to support risk management, like provision of specific insurance schemes or funding for irrigation technologies, than others. This needs to be considered especially in the communication through extension services. This is the first study, which incorporates farmers' risk attitudes and perceptions when classifying farmers for more target-oriented policy design.

An explicit limitation of the study is that although the clustering based on hard facts and quantitative data generally represents a solid fundament, deeper explanations of reasons and motives are missing. Another limitation lies in the fact that, although the investigated sample is relatively large, it still deviates in some variables from other surveys of South African small-scale farmers. Here, representativeness could be further improved in future surveys.

Notes

1. According to the National Development Plan, these are the main drivers that have significant effect the small-scale farming sector to enhance and build the rural economy (Carelsen *et al.*, 2021; DAFF, 2018).
2. Due to its ubiquity, we did not include Maize in our analysis, as all the farmers cultivate this crop as the staple food and not diversified among farmers.
3. Legumes include peanuts, Bambara nuts (*Vigna subterranea* L.), cowpea.
4. Fruits such as Mango, banana.
5. Vegetables include tomato, onion, cabbage.

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Appendix

For the robustness check of the clusters, we employed K-mean clustering approach with the Elbow method. The context and definitions of the clusters were confirmed the optimal number of four clusters for the small-scale farming systems in SA, similar to PAM results. The results are as follows:

Table A1 shows the k-mean clustering results for the small-scale farmers in RSA.

Cluster Names Number of members	Subsistence oriented 73	Semi-subsistence livestock-oriented 46	Semi-subsistence crop-oriented 69	Market-oriented 24	Overall significance
Farmer characteristics					
age	69.7 (10.5)	68.9 (11.0)	63.9 (9.77)	59.1 (12.9)	<0.001
gender	0.41 (0.50)	0.57 (0.50)	0.45 (0.50)	0.96 (0.20)	<0.001
educ	2.70 (3.58)	4.52 (4.89)	5.13 (4.77)	10.40 (5.62)	<0.001
Job_offFarm	0.29 (0.46)	0.13 (0.34)	0.14 (0.35)	0.38 (0.49)	0.02
Inc_socio	27166 (13079)	31351(16695)	24720 (15164)	21970 (17611)	0.05
Inc_remit	5814 (13923)	3916 (15026)	3210 (7481)	2400 (9908)	0.51
Risk_att	3.64 (2.51)	4.33 (3.11)	4.35 (2.93)	6.08 (2.39)	0.004
Farmer characteristics					
Farm_area	2.64(2.15)	3.99 (3.36)	4.13 (6.49)	11.7 (10.9)	<0.001
Cult_area	1.96 (1.55)	3.18 (3.22)	2.54 (2.11)	7.35 (6.06)	<0.001
Winter_fallow_area	0.85 (0.34)	0.69 (0.43)	0.72 (0.42)	0.25(0.36)	<0.001
Nr_winterCrops	0.14 (0.79)	0.09 (0.28)	0.07 (0.26)	1.46 (0.88)	<0.001
Cr_vegetables	0.01 (0.12)	0.07 (0.25)	0.10 (0.30)	0.88 (0.34)	<0.001
Cr_fruits	0.08 (0.28)	0.33 (0.47)	0.67 (0.47)	0.04 (0.20)	<0.001
Cr_legumes	0.85 (0.36)	0.50 (0.51)	0.49 (0.50)	0.29 (0.46)	<0.001
SaleValue_cropShare	0.00 (0.00)	0.30 (0.34)	0.70 (0.25)	0.92 (0.15)	<0.001
SaleValue_animShare	0.00 (0.00)	0.17 (0.11)	0.01 (0.05)	0.19 (0.26)	<0.001
Animal	0.38 (0.49)	1.00 (0.00)	0.49 (0.50)	0.67 (0.48)	<0.001
Nr_cattle	0.84 (1.96)	12.10 (13.80)	1.90 (3.79)	9.58 (13.5)	<0.001
Inc_onFarm	0.00 (0.00)	16807 (21276)	2837 (3421)	181523 (323210)	<0.001
Inc_onFarm_crops	0.00 (0.00)	0.08 (0.11)	0.97 (0.09)	0.72 (0.34)	<0.001
Inc_onFarm_anim	0.00 (0.00)	0.90 (0.18)	0.03 (0.09)	0.28 (0.34)	<0.001
Resource management and external incentives					
OwnTractor	0.01 (0.12)	0.02 (0.15)	0.01 (0.12)	0.38 (0.49)	<0.001
Water source	0.66 (0.89)	0.87 (0.98)	1.13 (0.86)	2.50 (0.66)	<0.001
Irrigation_Time	0.00 (0.00)	0.00 (0.00)	8.29 (45.1)	785 (559)	<0.001
Irrigation_Method	0.00 (0.00)	0.00 (0.00)	0.04 (0.27)	1.83 (0.48)	<0.001
PesticideUse	0.07 (0.25)	0.04 (0.21)	0.09 (0.28)	0.67 (0.48)	<0.001
FertilizerUse	0.32 (0.47)	0.26 (0.44)	0.20 (0.41)	0.71 (0.46)	<0.001
Employee_Permanent	2.84 (24.2)	8.31 (41.4)	0.00 (0.00)	404 (667)	<0.001
Employee_Seasonal	9.18 (22.0)	7.95 (16.9)	14.3 (48.1)	68.7 (142)	<0.001
OnFarmMarket	0.00 (0.00)	0.87 (0.34)	0.94 (0.24)	0.67 (0.48)	<0.001
OffFarmMarket	0.00 (0.00)	0.09 (0.28)	0.14 (0.35)	0.92 (0.28)	<0.001
CreditAccess	0.03 (0.16)	0.09 (0.28)	0.04 (0.21)	0.50 (0.51)	<0.001
Invest_past5Yrs	0.19 (0.40)	0.28 (0.46)	0.45 (0.50)	0.88 (0.34)	<0.001
ExtVisits_Yr	0.75 (1.51)	0.61 (0.71)	1.26 (6.23)	4.54 (6.19)	<0.001

Source(s): Authors' own creation/work

Table A1.
Results of k-mean clustering

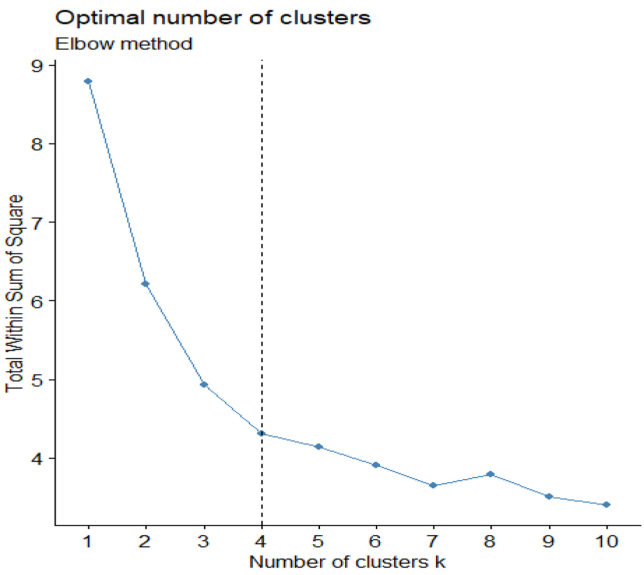

Figure A1.
Optimal number of clusters according to the Elbow method

Corresponding author
Jan-Henning Feil can be contacted at: feil.jan-henning@fh-swf.de