Land Use Policy 117 (2022) 106116

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Farming system diversity and its drivers in land reform farms of the Waterberg District, South Africa

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ARTICLE INFO

Keywords:
Farming systems
Typology
Land reform
Land use activities
Multivariate analysis

ABSTRACT

South Africa implemented land reform for the past two decades to contribute to addressing challenges posed by inequality, poverty and unemployment. Systematic classification of farming system types in land reform is lacking, and distinguishing the types with common characteristics (e.g. farm size, land use activities and livelihood strategies) is essential for implementing targeted agricultural development. In addition, understanding the drivers that lead to different farming system types might contribute to policy making and design of well-suited management options. We investigated 50 land reform farms in the Waterberg District, South Africa. We used principal component analysis (PCA) and two-step cluster analysis to assess the diversity of farming system types and factors driving such diversity. Indicators characterising the ruminant, monogastric, horticulture and crop farming, land use, and economic importance were collected to assess the target-farms and included in the PCA. Four farming system types were distinguished: crop plus ruminants- CR, horticulture- H, ruminants- R, and monogastric- M. The presence of type CR and R was driven by land reform policies which transferred farms of large sizes (± 1160 ha) for extensive resource use, in cognisance of the semi-arid conditions of the study area. Land reform policies drove the presence of the type H and M by targeting capital endowed farmers and areas with potential for horticulture, and by ensuring that farmers are physical capital endowed. Capital endowed farmers were in all four identified farming system types, be that as it may, limited external physical and financial capital support restricted capital poor farmers to type CR and M.

1. Introduction

Land reform programmes are initiatives in which nations attempt to correct inequalities in ownership and access to land, by re-allocating the land from the land-endowed (previous landowners) to the landless (new landowners) (Binswanger-Mkhize et al., 2009; SEAMEO (Southeast Asian Ministers of Education Organisation), 2000; World Bank, 1975). Previous landowners may be compensated for their land, during the implementation of these initiatives. Globally, countries which implemented agrarian reform or land reform have struggled to attain synergy between the social and economic objectives of land reform programmes (Binswanger-Mkhize et al., 2009). In the past two decades, land reform implementation in South Africa (SA) experienced such a dilemma (Keswell and Carter, 2014; Valente, 2011); different sub-programmes were implemented with different objectives and a diversity of outcomes can be observed. In South Africa (SA), the initial programmes were socially oriented, and this resulted in social diversity of new landowners. However, in recent years, the programmes aimed at establishing farmers with good economic performance by giving land mainly to those with financial resources to use it (Binswanger-Mkhize, 2014; Kepe and Hall, 2016; Netshipale et al., 2017). Not only institutional drivers can be attributed to the existence of land reform farms since the farms also vary for example, in natural capital (water availability and soil types) and physical capital (equipment and

Abbreviations: BIC, Bayesian Information Criterion; CA, Cluster Analysis; CR, Crop plus ruminants; H, Horticulture; M, Monogastric; PCA, Principale Component Analysis; R, Ruminant.

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https://doi.org/10.1016/j.landusepol.2022.106116
Received 26 June 2020; Received in revised form 24 January 2022; Accepted 22 March 2022
Available online 6 April 2022

infrastructure) endowments. Variations in institutional drivers, and natural and physical capital endowments of land reform farms are anticipated to influence agricultural land use (Alvarez et al., 2018; Chikowo et al., 2014; Köbrich et al., 2003; Senthilkumar et al., 2009; Tittonell et al., 2010) and the success of policies and interventions implemented for further development of these farms (Graskemper et al., 2021; Guarín et al., 2020; Olén et al., 2021; Ribeiro et al., 2021).

Farming system research is applied to better understand agricultural land use, its drivers and to design strategies for development (Giller, 2013). Further, farming system research focuses on decisions regarding production and consumption taken by a farming household (Garrity et al., 2012; Kuivanen et al., 2016; Migose et al., 2018; Zantsi et al., 2021). In this study, we consider a farming system to be "a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and for which similar development strategies and interventions would be appropriate" (Dixon et al., 2001:2). Identifying farming system types allows a shift from broader generalisation towards targeted, context-based development approaches based on identified challenges and opportunities, which may differ among types (Garrity et al., 2012; Giller, 2013; Guarín et al., 2020; Kuivanen et al., 2016; Zantsi et al., 2021).

The types of variables used to explore farming system diversity vary and depend on the purpose of the classification (Garrity et al., 2012; Graskemper et al., 2021; Köbrich et al., 2003; Kuivanen et al., 2016; Olén et al., 2021; Zantsi et al., 2021). Farming system typologies are of two kinds: structural which focuses on structural variables and functional which focuses on decisions made by farmers regarding production and consumption (Tittonell et al., 2005). Statistical methods used to explore farming system diversity often include a combination of multivariate analysis (like principal component and factor analysis) with cluster analysis and Bayesian systems (Alvarez et al., 2018; Berre et al., 2019; Bhattarai et al., 2017; Cortez-Arriola et al., 2015; Guarín et al., 2020; Kuivanen et al., 2016; Paas and Groot, 2017; Tittonell et al., 2010). These methods group farms around key characteristics with an aim to increase variation between groups and to decrease it within a group. To our knowledge, no studies have systematically classified farming system types in land reform farms of SA, and we envisage that the results will contribute towards sustainable economic use of these farms. The aim of this study is to generate systemic knowledge on farming systems in land reform farms of the Waterberg District in South Africa (SA). Towards this aim, we identified principal variables underlying the diversity in land use, classified farming system types, characterised the identified types, and analysed the drivers of the diversity among types.

2. Methods

2.1. Study area

We conducted the study in the Waterberg District Municipality (WDM) of the Limpopo Province, South Africa (SA). The district is classified as semi-arid with poor water resources and limited areas with high potential for crop production, although most of the land in the district is used for commercial farming (Nhemachena et al., 2011; WDM (Waterberg District Municipality), 2014:85). WDM has limited agro-ecological potential for arable farming, like most districts in SA, but typically agriculture is still the dominant land use in the area (GCIS (Government Communication and Information System), 2018). The climate of WDM is characterised by a mean annual rainfall of 577 mm, mean annual evaporation of 2100 mm, aridity index of 0.3 and average daily temperatures of 11.9 °C minimum and 27.2 °C maximum (M'Marete, 2003). The total annual rainfall is reported to be consistent over the past two decades, but the scenarios project an increase between 1 and 2 °C in temperature by 2035 (Adeola et al., 2019; DEA Department of Environmental Affairs, (2013)). Three (3) agricultural practices can be observed in this region: cash and field crop production, horticulture and livestock production (WDM (Waterberg District Municipality), 2005). According to WDM (Waterberg District Municipality) (2005:14) "cash and field crops encompassed cotton, sunflower, maize, wheat, sorghum, soya bean, groundnut, lucerne, paprika, tobacco, potato and watermelon; horticultural crops encompassed grape, citrus, peach, plum and vegetables; and livestock encompassed laying hens, broilers, pig, dairy, beef cattle, game and crocodile."

We selected four of six local municipalities (Bela-Bela, Lephalale, Mogalakwena and Mookgopong) of the WDM as the study area, based on prevalence of land reform farms (DRDLR (Department of Rural Development and Land Reform), n.d.). The respective contributions of the selected local municipalities to the district were: Bela-Bela 7%, Lephalale 40%, Mogalakwena 12% and Mookgopong 9% for land area, and Bela-Bela 10%, Lephalale 17%, Mogalakwena 45% and Mookgopong 5% for population (LDRT (Limpopo Deprtment of Road and Transport), 2012; WDM (Waterberg District Municipality), 2014).

2.2. Farm selection and data collection

In SA, land reform farms were established under two programmes: restitution (Rest) and redistribution (DLA (Department of Land Affairs), 1997, 2006; MALA (Ministry for Agriculture and Land Affirs), 2001). The Rest programme has not changed since inception, whereas the redistribution programme has changed with time. The redistribution programme was called Settlement or Land Acquisition Grant- SLAG from 1995 to 2000, Land Redistribution for Agricultural Development phase 1- LRAD1 from 2001 to 2007, Land Redistribution for Agricultural Development phase 2- LRAD2 from 2008 to 2010, and Proactive Land Acquisition Strategy- PLAS from 2006 to date (Kepe and Hall, 2016). Hence, in this paper, land reform farms fall under the following policy models: - Rest, SLAG, LRAD1, LRAD2 and PLAS, as shown in Table 1.

In the study area, farmers under SLAG belongs to households that are physical and financial capital poor, whereas farmers under Rest, LRAD1, LRAD2 and PLAS belongs to households that are physical and financial capital endowed (Netshipale et al., 2020). Farms have different ownership types: Farms are owned by households in groups (group-owned) under Rest and SLAG models, whereas farms under LRAD1, LRAD2 and PLAS models are either group-owned or owned by households individually (individual-owned) (DLA (Department of Land Affairs), 1997, 2006; MALA (Ministry for Agriculture and Land Affirs), 2001; Netshipale et al., 2017; Wegerif, 2004). Active households took land use decisions as a collective in group-owned farms, whereas a single household took land use decisions in individually owned farms. In this paper, the way land use decisions were taken in a farm is considered a proxy for 'farm organisational arrangements'. Group-owned farms had different operation styles: 'collective farming'- where land was used for the benefit of households as a collective, 'individual farming'- where land was used for the benefit of households independently from each other, and 'dual farming'- where land was use for collective and individual farming, this is in line with Lahiff (2007). We targeted 76 of the 140 land reform farms in the study area based on our knowledge of their accessibility and the willingness of beneficiaries to participate. Of the 76 targeted farms, we investigated 50 and did not find respondents that were willing or able to complete the survey in 26 farms. Investigated farms were differentiated according to land reform models, farm ownership type and farm operation style, as shown in Table 1. In each of the surveyed farms, we targeted at least 15% of the 'active households' for data collection. A household was considered active when it had 'at least one household member on a beneficiary list[2] of a farm and also at least one household member (either a beneficiary or non-beneficiary)

[2] Beneficiary lists were issued on land transfer either by the Department of Land Affairs (DLA) for farms transferred before 2009 or the Department of Rural Development and Land Reform (DRDLR) for farms transferred from 2009 onwards.

Table 1
Targeted and investigated farms, across land reform (LR) policy models, and distribution of investigated farms within ownership types and operation styles.

Farms				Distribution of investigated farms Farm ownership type			
				Individual	Group Farm operation style		
LR policy model[a]	Land user social class	Targeted	Investigated		Collective	Individual	Dual
Rest	Better-off	16	7	0	1	1	5
SLAG	Poor	6	4	0	1	1	2
LRAD1	Better-off	13	11	5	3	2	1
LRAD2	Better-off	34	21	8	9	3	1
PLAS	Better-off	7	7	5	2	0	0
Total	Better-off	76	50	18	16	7	9

[a] Rest–Restitution, SLAG–Settlement/Land Acquisition Grant, LRAD1–Land Redistribution for Agricultural Development phase 1, LRAD2–Land Redistribution for Agricultural Development phase 2, PLAS–Proactive Land Acquisition Strategy.
Sources: Netshipale et al. (2017) except information on investigated farms.

involved in farm management or land use' (Netshipale et al., 2017:59). The distance between farms and the nearest urban centres were recorded and were considered proxy for 'farm location'. Three locations were identified: the urban location at less than 16 km distance, peri-urban location between 16 and 40 km and rural location at above 40 km.

The Rapid Rural Appraisal (RRA) approach (Chambers, 1981) was used to gather information from 81 active households (11.9%[3] and 29.7% of active households in targeted and investigated farms, respectively). Using semi-structured questionnaires, we interviewed respondents who are either household heads or their representatives. We collected qualitative and quantitative data for the 2013/2014 agricultural year by asking recall data for the 12 months before the date of interview. Data about the agricultural activities being practiced being livestock farming (with distinctions among species), horticulture farming and crop farming (with distinctions among cultivars, for both), and combinations of these activities, and the land use associated with each of the agricultural activities, were collected under *land use*. Data about agricultural commodities produced, quantities produced, quantities sold and produce not for sale were collected under *income generation*. Data about the use of production factors and associated costs were collected under *production costs*. In the study area, production inputs were acquired mainly from formal markets, whereas agricultural produce was sold on both formal and informal markets. Remuneration of hired labour was pre-determined[4] in this study, as it was governed by the Basic Conditions of Employment Amendment Act, no 20 of 2013 (DOL (Department of Labour), 2014). This paper adopts the descriptions of formal and informal markets as given by Ferris et al. (2014). Informal markets operate outside of the taxation system, with no prescribed quality standards and volumes of goods, whilst the opposite suffices for formal markets. Examples of informal markets for produce are sales which take place at farm gate, roadside, village and rural gathering, and examples of formal markets on the other hand, comprises retailers, fresh produce markets and livestock auction. For each of the agricultural commodities produced, data about the type of market used to sell the produce was collected under *market type for produce*. We conducted focus group discussions (FGDs) with representatives of active households (in group-owned farms) to collect data about *farm organisational arrangements*, *farm physical capital endowment* (infrastructure and equipment) and households' *access to farms' natural, physical, financial and social capitals*. In farms owned by households individually, data about *farm physical capital endowment* was collected from the respondents. In instances where respondents were unsure, transect walks were taken (on farm) to verify the existence of listed activities and to assess the extent of agricultural land use. To understand the drivers of farming systems, we cross-examined the findings of this study on farm organisational arrangements, farm physical capital endowment and market types for produce. The knowledge generated from those cross-examinations was used to make deductions about the influence which the aforementioned factors had on the presence and emergence of farming system types.

2.3. Determination of input costs and income from sales

We considered farms as economic units in which investments are made with intent to generate income and to create wealth; hence, we excluded the bank and insurance values of livestock farming (Oosting et al., 2014). Extensive farming systems is used synonymously to low-input, low-output farming systems and intensive farming systems is used synonymously to high-input, high-output farming systems (Nemecek et al., 2011). A herd was considered natural capital as it encompassed livestock that, during the next six months, was not intended for sale or to be used for home consumption and donations (i.e. produce not for sale). Farm income referred to cash received (actual from sales and the opportunity value for produce not for sale) in exchange for provision of farm produce. The opportunity value was the monetary equivalent estimated based on market prices obtained for the same commodities.

Most households did not keep formal records of farming activities, in line with Cousins (2013), and they provided information based on recall. Seventy-two percent (72%) of the farms had complete information and we estimated production costs and income for the remaining 28% of the farms using prices for inputs and produce which prevailed in the study area for the market type they participated in, for the period under investigation. These prices are given in Table 2. We used an average exchange rate of R10.19/US$ for April 2013–March 2014 to convert South African Rand (R) to United Sates Dollar (US$). Further, the costs of other production inputs not covered in Table 2 were estimated based on survey data for this study as follows: (i) land preparation cost for vegetable production = US$83.4/ha (without own tractor) and US $49.1/ha (with own tractor), (ii) fertiliser price = US$0.5/kg (for both vegetables and crops), (iii) cost for vegetable seeds = US$65.5/ha and pesticides plus herbicides = US$71.3/ha, and for dry land crops seeds = US$58.9/ha and pesticides plus herbicides = US$24.5/ha, and (iv) cost of family labour = US$223.3/person/month (minimum wage for farm worker, 2013/2014 financial year).

The next section explains the process followed to determine farming costs and income. The process was the same for group-owned farms used for collective farming and for individual-owned farms but was different for group-owned farms that were used for individual, and dual farming. Collective farming meant a group of households pooled the capitals (natural, physical, financial, social and human) required (at cost to their household) for farm operations together and the farm income generated

[3] Estimated by authors based on information in Table 4 in Netshipale et al. (2017).

[4] http://www.mywage.co.za/...imum-wages/minimum-wages-2013-14/minimum-wages-for-farm-workers-from-march-1-2013-to-feb-28-2014 Accessed June, 2016.

Table 2
Commodities, their rate of usage and prices (US$), used to estimate farming costs and income.

Commodity	Price of input	Price of produce	
		Formal market	Informal market
Crop & horticulture	Fertiliser ($/ha)	$/ton	($/unit)
Maize	28.5[1]	187.9[3]	–
Sunflower	28.5[1]	456.0[3]	–
Swiss chard (Spinach)	522.1[2]	241.9[5]	0.3/ bundle[1]
Sweet potatoes	357.2[2]	406.4[4]	–
Butternut	357.2[2]	2 53.8[3]	–
Pumpkins	357.2[2]	222.1[3]	–
Gems squash	357.2[2]	3 49.4[4]	–
Chilli (green)	357.2[2]	905.1[5]	–
Tomatoes	714.4[2]	530.9[3]	7.9/crate, 2.8/box & 1/ packet[1]
Cabbage	604.5[2]	213.9[3]	0.8/head[1]
Green pepper	467.1[2]	609.4[5]	–
Green beans	274.8[2]	883.2[4]	–
Potatoes	604.5[2]	331.6[3]	–
Beetroot	329.7[2]	376.8[4]	–
Green peas	288.5[2]	322.2[4]	–
Onion	659.5[2]	350.1[3]	–
Watermelon	90.0[1]	124.6[4]	–
Citrus (oranges)	247.9[1]	203.6[3]	–
Table grapes	35.0[1]	1057.0[3]	–
Livestock	Feed ($/kg)	$/kg	($/animal)
Cattle	–	2.9[3]	686.9[1]
Milk (cow)	–	0.4[3]	–
Sheep	–	–	88.3[1]
Goat	–	–	68.7[1]
Pig	0.5[1]	2.0[3]	58.9[1]
Broiler	0.6[1]	1.8[3]	3.6[1]
Eggs (laying hens)	0.5[1]	1.1/dozen[3]	–

Sources: [1] Estimated by authors based on survey data for this study.
[2] Adapted by authors based on Department of Agriculture (DoA) (2008), Vegetable production in a nutshell, Pretoria: DoA, Retrieved from http://www.nda.agric.za/docs/infopaks/vegprodnutshell.pdf Accessed June, 2016.
[3] Department of Agriculture, Forestry and Fisheries (DAFF) (2015), Trends in the agricultural sector 2014, Pretoria: DAFF, Retrieved from http://www2.senwes.co.za/Files/main_productsservices/agriservices/2015/Trends2014.pdf Accessed June, 2016.
[4] Adapted by the authors based on Department of Agriculture, Forestry and Fisheries (DAFF) (2012), Abstract of agricultural statistics 2012, Pretoria: DAFF, pages 43 (Table 43) & 57 (Table 57), Retrieved from http://www.nda.agric.za/docs/statsinfo/Abstract_2012.pdf Accessed June, 2016; and based on source 2 (page 50, other vegetables).
[5] Adapted by authors based on prices from Johannesburg Market for the 13 June 2016, Available at http://www.joburgmarket.co.za/dailyprices.php Accessed 13 June 2016; and Department of Agriculture, Forestry and Fisheries (DAFF) (2016), Trends in the agricultural sector 2016, Pretoria: DAFF, pages 59, Retrieved from http://www.daff.gov.za/Daffweb3/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/.Trends%20in%20the%20Agricultural%20Sector%202016.pdf Accessed July, 2017.

belonged to the collective.

Therefore, in collective farming, as in individually owned farms, the costs and income were for the farm as an entity. On the contrary, in group-owned farms with individual farming, costs were incurred, and income was earned by a household independently from other households that used the same farm. In group-owned farms with dual farming, costs were incurred, and income earned by independent households and also by farms as entities. Hence, in each of these farms, we determined the overall total (farming costs or farm income) by adding the total estimated for the entity to the total estimated for individual farming.

2.3.1. Group-owned farms with collective farming and individual-owned farms

Gross agricultural cost (GAC_i) and gross agricultural income (GAI_i) of the i^{th} farm were estimated as:

$$GAC_i = \sum_{k=1}^{n} CP_k N_{ki} \tag{1}$$

where N_{ki} was the number of the units of the k^{th} agricultural input purchased by the i^{th} farm, n was the types of agricultural inputs k and CP_k was the cost price per unit of the k^{th} agricultural input type.

$$GAI_i = \sum_{l=1}^{n} SP_l N_{li} \tag{2}$$

Where N_{li} was the number of the units of the l^{th} agricultural product sold by the i^{th} farm, n was the types of agricultural products l and SP_l was the sale price per unit of the l^{th} agricultural product.

2.3.2. Group-owned farms with individual farming

The cost of the k^{th} agricultural input CK_j and income from the l^{th} agricultural product IL_j for the j^{th} household were estimated as:

$$CK_j = CP_k N_{kj} \tag{3}$$

and

$$IL_j = SP_l N_{lj} \tag{4}$$

where CP_k was the cost price per unit of the k^{th} agricultural input and N_{kj} was the number of the units of the k^{th} agricultural input purchased by the j^{th} household, and SP_l was the sale price per unit of the l^{th} agricultural product and N_{lj} was the number of the units of the l^{th} agricultural product sold by the j^{th} household.

Whereas the cost of the k^{th} agricultural input CK_i and income from the l^{th} agricultural product (IL_i) for the i^{th} farm were estimated as:

$$CK_i = \left(\frac{\sum_{j=1}^{n} CK_{ji}}{n_{ji}} \right) NK_{ji} \tag{5}$$

and

$$IL_i = \left(\frac{\sum_{j=1}^{n} IL_{ji}}{n_{ji}} \right) NL_{ji} \tag{6}$$

where CK_{ji} was the cost of the k^{th} agricultural input for the j^{th} household that farmed in the i^{th} farm, IL_{ji} the income from the l^{th} agricultural product for the j^{th} household that farmed in the i^{th} farm and n the number of households; n_{ji} was the number of households (sample) with available data on variable under consideration in the i^{th} farm; and Nk_{ji} and Nl_{ji} were numbers of households (population) conducting similar activity in the i^{th} farm.

Gross agricultural cost (GAC_i) and agricultural income (GAI_i) for the i^{th} farm were estimated as,

$$GAC_i = \sum_{k=1}^{n} CK_i \tag{7}$$

and

$$GAI_i = \sum_{l=1}^{n} IL_i \tag{8}$$

where CK_i was the cost of the k^{th} agricultural input purchased by the i^{th} farm and IL_{ji} was the income from the l^{th} agricultural product sold by the i^{th} farm, and n was either input types or product types.

2.3.3. Group-owned farms with dual farming

For the i^{th} farm, gross agricultural cost (GAC_i) was estimated by adding Eq. (1) and Eq. (7) (i.e., Eq. (9)), and gross agricultural income (GAI_i) was estimated by adding Eq. (2) and Eq. (8) (i.e., Eq. (10)). Therefore, Eqs. (9) and (10) were:

$$GAC_i = \left(\sum_{k=1}^{n} CP_k N_{ki}\right) + \left(\sum_{k=1}^{n} CK_i\right) \tag{9}$$

and

$$GAI_i = \left(\sum_{l=1}^{n} SP_l N_{li}\right) + \left(\sum_{l=1}^{n} IL_i\right) \tag{10}$$

In all farm ownership types and operational styles, farm gross margin (GM_i) for the i^{th} farm was estimated by subtracting Eq. (1) from Eq. (2) or Eq. (7) from Eq. (8) or Eq. (9) from Eq. (10).

Livestock numbers were converted to tropical livestock units (TLUs) for standardisation, with a TLU representing a hypothetical animal of 250 kg live weight, using the following conversion factors: - cow = 0.7, sheep or goat = 0.1, pig = 0.2 and chicken = 0.01 (HarvestChoice/IFPRI, 2011). Animals had offspring of varying ages which led to adjustments of conversion factors as follows: - calf = 0.35, kid or lamb = 0.05 and piglet = 0.1.

Farm gross margin per hectare (GM/ha) and gross margin per TLU (GM/TLU) were estimated as:

$$(GM/ha)_i = (GIC_i - GCC_i)/hectares \quad used \quad for \quad crops \tag{11}$$

and

$$(GM/TLU)_i = (GII_i - GCL_i)/TLUs \quad sold \tag{12}$$

where GIC_i was the gross income from crop production and GCC_i is the gross costs of crop production, and GIL_i was the gross income from livestock production and GCL_i was the gross costs of livestock production, of the i^{th} farm.

2.4. Data analysis

We used Principal Component Analysis (PCA) and Cluster Analysis (CA) to generate a typology of farming systems in land reform farms. PCA was used to explore relationships between variables and to reduce

Table 3
Description of variables used for PCA (n = 50).

Variable	Label	Unit	Mean	SEM	Min.	Max.
Household						
Active households per farm	Activehhs	Number	6.98	1.85	1	55
Agricultural land use						
Farm size	Farmsize	Hectares	781.94	201.68	9	9254
Arable land	Arableland	Hectares	15.33	6.04	0	210
Crop land ratio[a]	Croplandratio	–	0.22	0.06	0	1
Horticulture land ratio[b]	Hortlandratio	–	0.38	0.07	0	1
Herd size[c] (livestock capital)	Herdsize	TLU[d]	51.1	11.40	0	391.2
Cost ratios[e]						
Crop	Cropcostratio	–	0.12	0.04	0	1
Horticulture	Hortcostratio	–	0.31	0.06	0	1
Ruminant	Rumcostratio	–	0.33	0.06	0	1
Monogastric	Moncostratio	–	0.23	0.06	0	1
Hired labour	Hirelabourratio	–	0.49	0.05	0	1
Income ratios[f]						
Crop	Cropincomeratio	–	0.09	0.03	0	1
Horticulture	Hortincomeratio	–	0.30	0.06	0	1
Ruminant	Rumincomeratio	–	0.36	0.06	0	1
Monogastric	Monincomeratio	–	0.23	0.06	0	1
Sale ratios[g]						
Crop	Cropsaleratio	–	0.15	0.05	0	1
Horticulture	Hortsaleratio	–	0.40	0.07	0	1
Ruminant	Rumsaleratio	–	0.50	0.07	0	1
Monogastric	Monsaleratio	–	0.25	0.06	0	1
Produce not for sale (PNS) ratios[h]						
Crop	CropPNSratio	–	0.02	0.01	0	1
Horticulture	HortPNSratio	–	0.20	0.05	0	1
Ruminant	RumPNSratio	–	0.21	0.05	0	1
Monogastric	MonPNSratio	–	0.19	0.05	0	1
Farm productivity						
Livestock sales	Livestocksales	TLU/yr	39.6	11.54	0	425.6
Farm gross margin[i]	Grossmargin	$/yr	17,408	5133.80	-17,890	207,263
Gross margin per hectare cultivated[j]	GMperhacultivated	$/ha/yr	627	282.08	-2412	6796
Gross margin per TLU[k]	GMperTLUsold	$/TLU/yr	30	180.86	-6811	1483

[a] Share of arable land used for crops (maize and sunflower).
[b] Share of arable land used for horticulture (citrus, grapes and vegetables).
[c] Animals that were on the farm during the day of the visit that were not to be sold within the next six months (i.e. breeding stock)
[d] Tropical livestock unit (TLU) computed using the following conversion factors: cow = 0.7, sheep or goat = 0.10, pig = 0.20, poultry = 0.01; Livestock offspring were of varying ages and the following conversion factors were used for offspring: calf = 0.35, kid/lamb = 0.05 and piglet = 0.1.
[e] Share of variable costs incurred by a specified land use activity or production item (i.e. crop, horticulture, ruminant and monogastric, or hired labour).
[f] Share of income generated by a specified land use activity (i.e. crop, horticulture, ruminant and monogastric).
[g] Share of value emanating from sales in relation to the total value generated from a specified land use activity (i.e. crop, horticulture, ruminant and monogastric).
[h] Share of produce used for non-sale purposes (used for home consumption and or donations) emanating from a specified land use activity (i.e. crop, horticulture, ruminant and monogastric).
[i] Income less production costs, when family labour and opportunity cost for land were ignored.
[j] Income from crop and horticulture production less costs incurred from crop and horticulture production divided by land area used for crop and horticulture production.
[k] Income from livestock production less costs incurred from livestock production divided by TLUs sold.

the dataset of 27 variables (Table 3) into a smaller number of principal components (PC's). Principal components were considered when having at least four variables with loading scores of > 0.60 (Pituch and Stevens, 2016). Variables which loaded > 0.5 on one of the PC's were retained and they became the reduced dataset (PCA output) which we used in a two-step cluster analysis (Constatini et al., 2010; Domínguez-Rodrigo et al., 2009; Dossa et al., 2011). We used the overall silhouette measure of cluster cohesion and separation, of the Bayesian Information Criterion (BIC), to determine the optimum number of clusters (Jain and Koronios, 2008; Rousseeuw, 1987). The number of clusters suggested by PCA was used as the starting point because this solution has a cluster cohesion and separation value of > 0.5, which indicate that the assignment of data points to cluster centres were clear (Kaufman and Rousseuw, 1990). We repeated the two-step cluster analysis with pre-specified number of clusters required (i.e., cluster numbers above the number suggested by PCA) to determine the number of clusters (optimum number of clusters) which yield the best cluster cohesion and separation value. The identified optimum number of clusters was used to repeat the two-step cluster analysis and created a variable named cluster group to ascertain which farms belong to a particular cluster. Kruskal-Wallis test was used to explore the differences among clusters in the 16 principal variables. Furthermore, for one of the clusters, descriptive statistics for five non-principal variables were considered because they described the key characteristics which differentiate that cluster from other clusters. The final clusters attained were described and given cluster names. Further, in cluster groups where two social classes of farmers (the capital poor and capital endowed) were included, differences in all 21 (16 principal and five non-principal) variables were explored between social classes using Mann-Whitney U tests. Fisher's exact test was used to compare distributions of farms within land reform policy models and within market types, across the farming system clusters. Statistical differences were only mentioned as significant when $P < 0.05$. For statistical analysis, SPSS version 26 statistical package (IBM Corp. Released, 2019) was used.

3. Results

3.1. Classification of farming system types

Table 3 provides description of variables used for PCA. We explored three principal components as each of these components had at least four variables with loading scores of > 0.60. Table 4 presents a PCA model summary and component loading. The three principal components (PC's) inclusively explained 60.4% of the variation in the data set. The first component (PC 1) explained 22.6% of the variation in the data and was related to ruminants, and second component (PC 2) explained 21.2% of the variation and was related to horticulture, as well as the third component (PC 3) which explained 16.5% of the variation and was related to crops.

The three PC's comprised 16 influential variables as shown by non-repeating variables which loaded > 0.5 on one of the PC's in Table 4. The relationships among the variables suggested four farming system types (i.e., monogastric, horticulture, ruminant and crop) for land reform farms in the study area (shown by red stars in Fig. 1: A and B). We considered the suggested four-cluster solutions for two reasons. Firstly, this solution had an overall silhouette measures of cluster cohesion and separation value of 0.6, which indicate that data points are clear assignment to cluster centres. Furthermore, this value shows that variations among farming system types was increased and variation within a farming system type was reduced. Secondly, cluster solutions above four were not excellent as they had cluster cohesion and separation values of 0.7.

3.2. Characteristics of farming systems in land reform farms

We defined four farming system types or farming systems: crop plus ruminant- CR, horticulture- H, ruminant- R and monogastric- M (Fig. 2), based on 16 principal variables identified using PCA. Furthermore, for M, descriptive statistics (mean ± sd) for livestock sales and the ratios for cost, income, sale and produce not for sale associated monogastric production(Fig. 1A) were also presented as they distinctively describe this farming system type. Crop farming was rain fed and prevailed the same in peri-urban (42.9%) and rural (57.1%) locations, whereas horticulture, under irrigation was based on relatively intensive resource use, was practiced in all locations, but prevailed the most in peri-urban location (50.0%). Ruminant farming entailed keeping cattle and/or sheep and/or goats on veld (natural grazing land) and was dominant in rural locations (76.5%), though it was also practiced in peri-urban locations. Monogastric farming was poultry or pig husbandry, based on relatively intensive resource use, and was practiced in all locations, but was most prevalent in urban (41.7%) and peri-urban (50.0%) locations.

Hired labour ratios were similar among farm types (ratio of 0.49, overall), an indication that, in each of the types, family labour (ratio of 0.51, overall, as total labour = 1) was used. We observed, in the study area, that fewer hired labourers were used (per farm per annum) in the types with extensive resource use i.e. CR (two permanent and ≤ five casual labourers for a period of a month) and R (two permanent labourers), compared to those used in resource-intensive type H (≥ ten casual labourers for a cumulative period equalling three months). However, the observed similarities between type H and the other types were because, in type H, family labour was permanent and hired labour was used occasionally (e.g. during planting, weeding and harvesting). Resources used were relatively intensive in type M, but the hired labour ratio of this type was like those of other types because of the low production scale (pig production based 5o sows or 600–1200 broiler chickens per batch), which could be practiced without hired labour.

Farm gross margins were similar among types (US$17408/yr, overall), an indication that each of the types was efficient in its own way. Farmers of type CR and R explained that livestock was rarely sold, as herd sizes were below the livestock carrying capacities of the farms.

Table 4
PCA model summary and component loading (n = 50).

Total Eigenvalue	16.298		
Total % variance	60.363		
	Dimension		
	1	2	3
Total Eigenvalue values	5.938	5.845	4.515
% of total variance	21.993	21.647	16.722
Label	Component Loadings		
Rumincomeratio	0.862	-0.127	-0.389
Rumsaleratio	0.797	-0.009	-0.258
Rumcostratio	0.791	-0.137	-0.483
Herdsize	0.712	-0.110	-0.335
Farmsize	0.580	-0.090	-0.285
RumPNSratio	0.546	-0.069	0.103
Activehhs	0.289	-0.150	-0.101
Hortcostratio	-0.413	0.855	-0.067
Hortincomeratio	-0.426	0.828	-0.088
Hortsaleratio	-0.436	0.775	-0.101
Monsaleratio	-0.607	-0.761	-0.033
Moncostratio	-0.633	-0.756	-0.011
Monincomeratio	-0.639	-0.751	-0.008
MonPNSratio	-0.560	-0.662	-0.001
Hortlandratio	-0.446	0.642	-0.299
GMperhacultivated	-0.258	0.580	-0.138
Livestocksales	-0.439	-0.574	-0.050
Grossmargin	-0.291	0.413	-0.008
HortPNSratio	-0.128	0.408	-0.061
Cropcostratio	0.309	0.041	0.891
Croplandratio	0.156	-0.003	0.883
Cropincomeratio	0.228	0.077	0.865
Cropsaleratio	0.216	0.042	0.843
Arableland	0.104	0.204	0.685
CropPNSratio	0.232	-0.054	0.388
GMperTLUsold	0.031	-0.045	0.073
Hirelabourratio	-0.011	0.018	-0.070

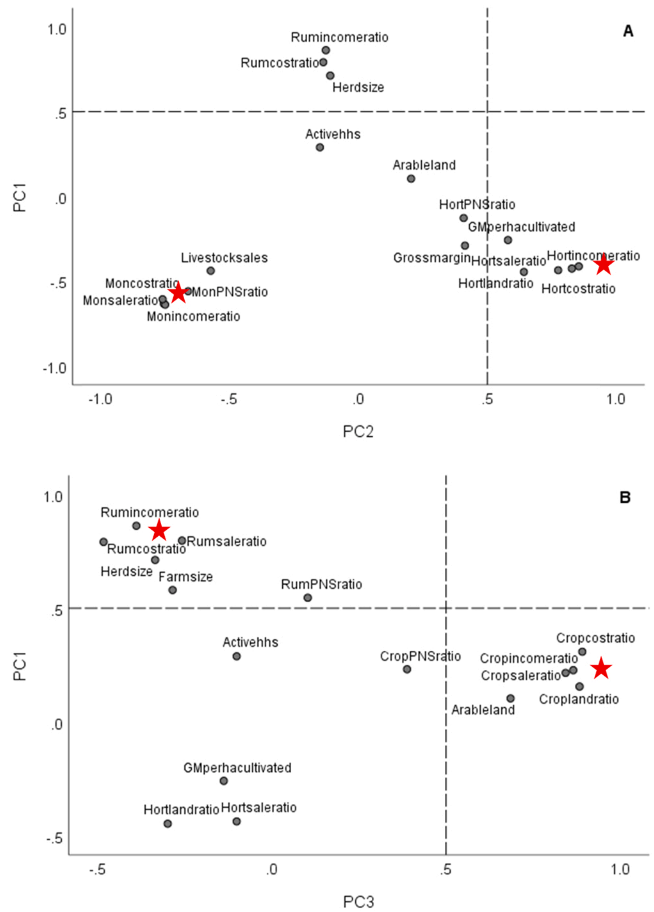

Fig. 1. Plots of component loadings from the PCA (A-B), with the cut-off for variable inclusion in cluster analysis at 0.5 and suggested farming systems shown by red stars.

Hence, the overall mean livestock sales for type CR and R was 9.7 TLUs/yr. We observed negative gross margins per hectare cultivated in CR, R and M farm types, which are shown in Table 6, and per TLU of US$-176/yr in H farm type. These negative gross margins indicated that the costs linked to either cultivation or animal husbandry surpassed the income generated by each of the practices, for the financial year covered in this study. The characteristics of farming system types explained below (mean ± se) are based on the 16 principal variables shown in Tables 5 and 6. We included five non-principal variables (i.e., livestock sales and the ratios for cost, income, sale and produce not for sale associated with monogastric production), to describe the characteristics of farms of type M, as they explained the agricultural activity which contributed the most to farm income and farming costs.

3.2.1. Crop plus ruminant–CR (14% of sampled farms)

Farms of type CR had medium to large farm size (676.7 ha) and a large area of arable land (78.5 ha). The arable land was used mostly for crops (ratio of 0.97) and least for horticulture. Herd size was medium (45.8 TLUs), and herds did not include monogastrics. CR farmers explained that mixed farming of ruminants and crops was the intended land use when land was transferred. Crops incurred most of the farming costs (ratio of 0.76) and generated most of the farm's income (ratio of 0.64), whereas ruminants also incurred costs (ratio of 0.11) and contributed to the farm's income (ratio of 0.32). Most of the crop produce was sold, with sales ratios of 0.81 for crops and 0.51 for ruminants. Ruminants had moderate contribution to produce not for sale. Gross margin per hectare cultivated was low (US$-30/yr).

3.2.2. Horticulture- H (28% of sampled farms)

Farming system type H had a relatively small farm size (318.5 ha) but had a relatively medium area of arable land (14.6 ha) which was used mostly for horticulture (ratio of 0.83) when compared to other types. The herd consisted of ruminants only (14.8 TLUs). At type H farms, horticulture incurred most of the farming costs and generated most of the farm's income, with ratios of 0.92 and 0.96, respectively. Most of the horticulture produce were sold (ratio of 0.99). Ruminants had low contribution to produce for sale. Gross margin per hectare cultivated was highest (US$2529/yr) and differed from low gross margins in all other farming system types.

3.2.3. Ruminant–R (34% of sampled farms)

Farms of type R had a significantly larger farm size (1644 ha) and a small area of arable land (0.4 ha). The arable land was used solely for horticulture at a low ratio of 0.24. The size of arable land and the ratio for the land used for horticulture changed to 1.6 ha and 1.00, respectively, when only the four R farms with arable activities were included. Farmers in R explained that horticulture was an added land use activity in an exploratory phase because the activity was not included on the farm business plan when their land was transferred. Ruminant farming (based on extensive resource use) was the dominant farm activity in R farms, as reflected by the significantly larger herd size of 116.8 TLUs, which differed from small herd sizes in type H and M. In R farms, ruminants incurred most of the farming costs (ratio of 0.91) and generated most of the farm's income (ratio of 0.97), whereas horticulture accounted for the residual costs and income. Most of the farm produce was sold, with sales ratios of 0.96 for ruminants (for all R farms) and 0.82 for horticulture (for R farms with arable activities). Ruminants had moderate contribution to produce not for sale. Gross margin per hectare cultivated was low (US$-88/yr) and differed from high gross margin in type H.

3.2.4. Monogastric–M (24% of sampled farms)

Farms that fell under type M had the smallest farm size (162.5 ha) and very small areas of arable land (0.5 ha). The arable land was used for crop and horticulture at land ratios of 0.15 and 0.26, respectively. Herd size was relatively small at 3.5 TLUs, as animals kept for reproduction purposes were only a fraction of the herd in pig farms (sows and boars), and broiler farms did not keep those. In M farms, most of the animals were sold within a financial year, as reflected by livestock sales of 140.9 TLUs/yr. Farmers expressed two reasons for the observed livestock sales: firstly, in broiler farms, chicks were bought in batches and in each batch, the birds reached a targeted market weight of 2 kg in about 42 days, and secondly, in pig farms, sows gave birth to piglets that reached the targeted market weight of 90 kg in about five months. Monogastrics incurred most of the farming costs and generated most of the farm's income (ratios of 0.95 and 0.98, respectively). Most of the monogastric produce was intended for sale at ratio of 0.98 and monogastrics contributed the most at ratio of 0.76 to produce not meant for sale. The high contribution of monogastrics to produce not meant for sale showed that monogastric farming had a potential to alleviate household food insecurity. Gross margin per hectare cultivated was low (US$-196/yr).

The characteristics of the farming system types show that fewer farms are dominated by an irrigation reliant activity, horticulture, (28%: type H), whereas most of the farms are not irrigation reliant (72%: type CR, R and M combined).

3.3. Drivers of farming system types

We analysed the influence of land reform policy models plus capital endowments of farmers, organisational arrangements and physical capital endowments of farms, and market type for produce used, as drivers of farming system types. Table 7 shows the distribution of farms among farming system types, across policy models. Under Rest model,

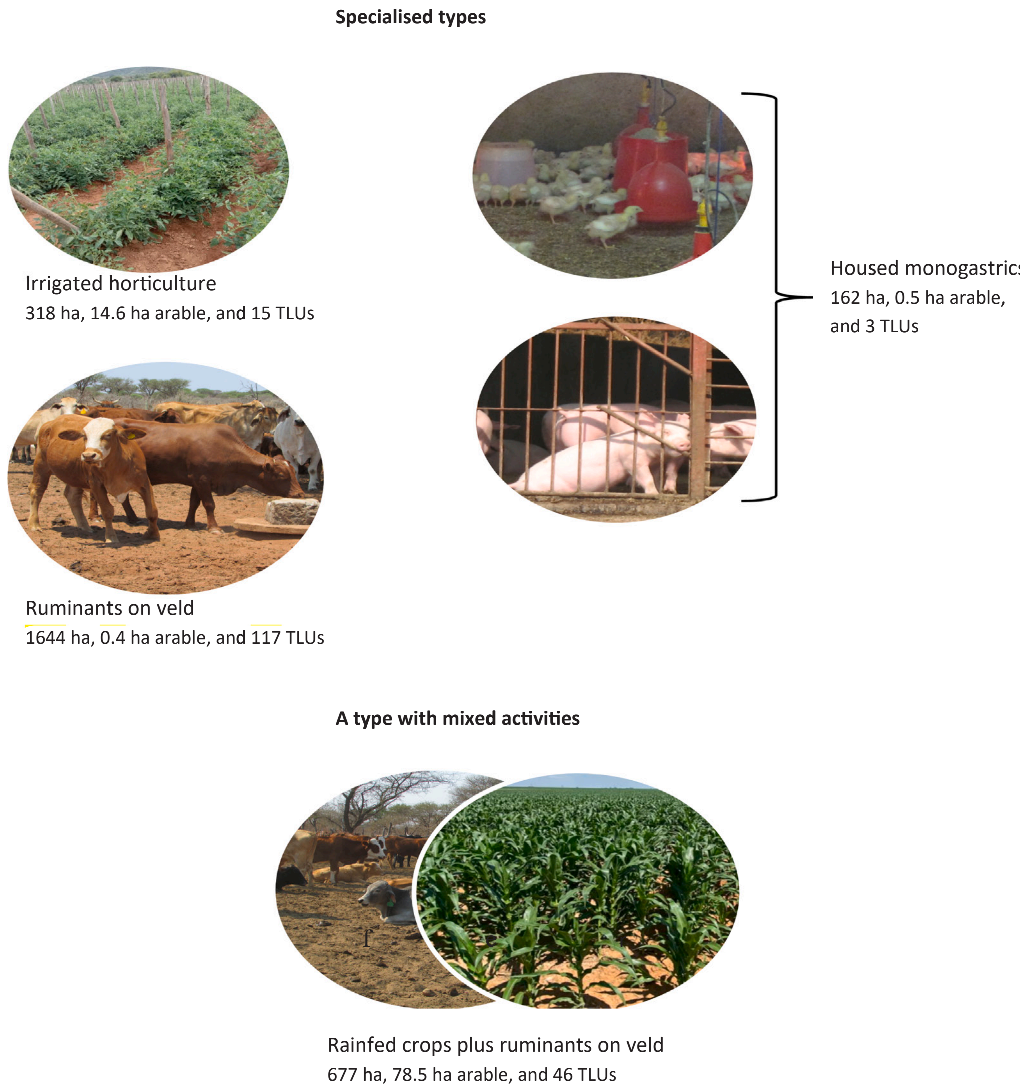

Fig. 2. Land use activities in the four farming system types.
(Sources: Authors).

Table 5
Farm characteristics (mean ± se) across the farming system types.

	Farming system type[a]			
	CR	H	R	M
Farms (n = 50)	7	14	17	12
Variable				
Farm size (ha)	676.7[ab] ± 391.73	318.5[ab] ± 136.95	1644.2[c] ± 503.00	162.5[a] ± 70.14
Arable land (ha)	78.5[c] ± 33.90	14.6[c] ± 6.10	0.4[a] ± 0.21	0.5[ab] ± 0.24
Crop land ratio	0.97[b] ± 0.024	0.17[a] ± 0.092	0.00[a] ± 0.000	0.15[a] ± 0.103
Horticulture land ratio	0.03[a] ± 0.024	0.83[b] ± 0.092	0.24[a] ± 0.106	0.26[a] ± 0.129
Herd size (TLUs)	45.8[ab] ± 28.30	14.8[a] ± 8.73	116.8[b] ± 23.57	3.5[a] ± 2.05

[abcd]Means with different superscripts within rows are statistically different (Kruskal-Wallis test, $P \leq 0.05$).
[a] CR-Crop plus ruminant, H–Horticulture, R–Ruminant, M–monogastric; TLUs–Tropical livestock units.

type R was most prevalent with five farms. Under the SLAG model, most prevalent were CR and M type of farms. All farming system types were observed under LRAD1 and there was no dominant type. Under LRAD2 model, type H and M were most represented, whereas under PLAS, only type R was represented. In this study, we observed that farmers of type CR and M type are of two capital endowment classes: capital poor and capital endowed. In both CR and M type, capital poor farmers were on farms where land ownership changed under the SLAG model. Capital endowed farmers of type CR were on farms where land ownership changed under Rest, LRAD1 and LRAD2, whereas those of type M were on farms where land ownership changed under LRAD1 and LRAD2. On the contrary, only capital endowed farmers (in the Rest, LRAD1, LRAD2 and PLAS) were found in type H and R. When comparing capital poor and capital endowed farmers, we found differences ($P < 0.05$) in ruminant sales ratios within type CR and farm gross margins within type M. Ruminant sales ratio was high (ratio of 0.99 ± 0.01) where CR was practiced by capital poor farmers than where CR was practiced by capital endowed farmers (ratio of 0.32 ± 0.44). This difference in ruminant sales ratios indicates that capital poor farmers are likely to sell ruminants, whereas capital endowed farmers are likely to use ruminants for products not meant for sale. Capital poor farmers of type CR explained that crop farming was dependent on the availability of external financial support. Farm gross margin was high (US$13157

Table 6
Economic characteristics (mean ± se) of farms, across farming system types.

	Farming system type[a]			
Farms (n = 50)	CR 7	H 14	R 17	M 12
Variable				
Crop farming ratios				
Cost	0.76[b] ± 0.064	0.05[a] ± 0.034	0.00[a] ± 0.000	0.01[a] ± 0.007
Income	0.64[b] ± 0.123	0.01[a] ± 0.012	0.00[a] ± 0.000	0.00[a] ± 0.000
Sales	0.81[b] ± 0.143	0.07[a] ± 0.071	0.00[a] ± 0.000	0.05[a] ± 0.053
Horticulture farming ratios				
Cost	0.13[ab] ± 0.082	0.92[c] ± 0.034	0.08[a] ± 0.057	0.03[a] ± 0.022
Income	0.03[ab] ± 0.031	0.96[c] ± 0.020	0.03[a] ± 0.018	0.02[a] ± 0.012
Sales	0.14[ab] ± 0.143	0.99[C] ± 0.008	0.19[a] ± 0.088	0.17[ab] ± 0.111
Ruminant farming ratios				
Cost	0.11[ab] ± 0.044	0.03[a] ± 0.015	0.91[c] ± 0.056	0.00[a] ± 0.004
Income	0.32[ab] ± 0.133	0.03[a] ± 0.018	0.97[c] ± 0.018	0.01[a] ± 0.005
Sales	0.51[ab] ± 0.183	0.21[a] ± 0.113	0.96[c] ± 0.013	0.07[a] ± 0.067
Produce not for sale	0.44[b] ± 0.171	0.05[a] ± 0.035	0.38[b] ± 0.116	0.01[a] ± 0.014
Gross margin				
US$/ha cultivated/yr	-30[a] ± 86.06	2529[b] ± 774.40	-88[a] ± 81.43	-196[a] ± 316.54

[abc]Means with different superscripts within rows are statistically different (Kruskal-Wallis test, $P \leq 0.05$).
[a] CR–Crop plus ruminant, H–Horticulture, R–Ruminant, M–monogastric; TLUs–Tropical livestock units.

Table 7
Distribution of farms (%) among farming system types, across land reform (LR) policy models.

		Farming system type[a]			
LR Policy model[b]	Farms (n =50)	CR	H	R	M
Rest	7	14,3[a]	14,3[a]	71,4[b]	0,0[a]
SLAG	4	50,0[b]	0,0[a]	0,0[a]	50,0[b]
LRAD1	11	18,2[a]	18,2[a]	36,4[a]	27,3[a]
LRAD2	21	9,5[a]	52,4[b]	4,8[a]	33,3[ab]
PLAS	7	0,0[a]	0,0[a]	100,0[b]	0,0[a]

[a] CR–Crop plus ruminant, H–Horticulture, R–Ruminant, M–monogastric.
[b] Rest–Restitution, SLAG–Settlement/Land Acquisition Grant, LRAD1–Land Redistribution for Agricultural Development phase 1, LRAD2–Land Redistribution for Agricultural Development phase 2, PLAS–Proactive Land Acquisition Strategy.
Tow-sided Fisher's exact test ($P = 0.000$ for LR policy model and farming system types), [abc]Different superscripts in a row indicate significant differences among farming system types [$\alpha = P(\chi 2 > 0.05;20)$].

± 4026.92/yr) for capital endowed type M farmers than for capital poor farmers of the same type (US$472 ± 304.00/yr). Capital endowed farmers of type M indicate that the number of production cycles of their animals is consistent whereas for the capital poor farmers of this type, the availability of external financial support determines their number of cycles. Therefore, the observed differences in farm gross margins between the capital endowment classes of farmers in type M could be attributed to the differences in the number of production cycles completed. In this study, variables not affected ($P > 0.05$) by capital endowment class were 15 and 20 for type CR and M, respectively.

Farm organisational arrangements did not differ between farming system types and in most of the farms (62%, overall) land use decisions were taken by an individual household. Farming system types did not differ in farm physical capital endowments, with most of the farms (70%, overall) being physical capital endowed. Table 8 shows distribution of farms between market types for produce sold, across farming system types. Most of the farms of the type H and R sold produce in formal markets, whereas most of the farms of the type CR and M sold their produce in informal markets. Type M farmers explain that they sold produce in informal markets because farm infrastructure (i.e., number and size of broiler houses) were insufficient for production levels required in formal markets. Farmers of type M had production scales of 600–1200 broilers per production cycle of 42 weeks which met demand in informal markets. We observed, in the study area, that the market types for produce were influenced by the commodities being sold (i.e., products from crop or horticulture or ruminants or monogastrics), but not by the capital endowment class of the farmer. Hence, we did not analyse the distribution of farms between market types for produce sold, across capital endowment classes of farmers within CR and M.

4. Discussion

4.1. Methodology

In this study, we adopted a positivist approach to develop a structural typology using multivariate techniques. Multivariate techniques were used because our focus was on cluster mean, and the techniques are repeatable and allow for comparison of results across scales and contexts (Kostrowicki, 1977; Kuivanen et al., 2016). Furthermore, the techniques allow users to select variables to be used for typology development and to determine the number of clusters, as the techniques acknowledge that typology research is subjective in nature (Dossa et al., 2011; Emtage et al., 2006; Gelbard et al., 2007; Guarín et al., 2020; Zantsi et al., 2021). Using PCA we identified three PC's comprised of 16 principal variables, and the plots of component loadings suggested four clusters. In this study, principal variables were subjected to two-step cluster analysis as this method was reported to have advantages compared to classical clustering methods like hierarchical clustering (Dossa et al., 2011; Emtage, Herbohn, and Harrison, 2006; Kostov and McErlean, 2006). Two-step cluster analysis suggested four clusters, and the flexibility of this method allowed us to explore cluster solutions from three up to

Table 8
Distribution of farms (%) between market types for produce sold, across farming system types.

	Farming system type[a]			
	CR	H	R	M
Farms (n =50)	7	14	17	12
Market type				
Formal	42,9[b]	85,7[d]	64,7[c]	8,3[a]
Informal	57,1[c]	14,3[a]	35,3[b]	91,7[d]

[a] CR–Crop plus ruminant farming, H–Horticulture farming, R–Ruminant, M–monogastric farming.
Two-sided Fisher's exact test ($P = 0.001$ for market type and farming system types), [abc]Different superscripts in a row indicate significant differences among farming system types [$\alpha = P(\chi^2 > 0.05;8)$].

seven. We decided to retain four-cluster solution because cluster solutions above four were not excellent, as they had overall silhouette measures (of the Bayesian Information Criterion- BCI) of cluster cohesion and separation values of ≤ 0.7 (Guarín et al., 2020; Jain and Koronios, 2008; Kaufman and Rousseuw, 1990).

The sample size, a limitation of this study, was small ($n = 50$) because we focused on active land reform farms in a context where their numbers are relatively small (both the active and total farms) (DRDLR (Department of Rural Development and Land Reform), n.d.; Netshipale et al., 2017), and participation was voluntary and based on the ability of a respondent to complete the survey. The power of multivariate analysis techniques is positively related to the number of the observations (Alvarez et al., 2018; Berre et al., 2019; Cortez-Arriola et al., 2015; Kuivanen et al., 2016; Paas and Groot, 2017; Tittonell et al., 2010), hence the sample size was a limitation. We could not use archetypal analysis in this study because the focus was on identifying universal patterns (Kok et al., 2016; Oberlack et al., 2016; Sietz et al., 2012; Tittonell et al., 2020; Václavík et al., 2013), and this method tends to have limitations regarding 'validity and boundaries of the archetypes, and selection of appropriate attributes' (Eisenack et al., 2019). This study provides a snapshot of farming systems which existed in land reform farms during the study period, 2013–2014, as farming systems are dynamic by nature (Kuivanen et al., 2016; Tittonell et al., 2010).

4.2. *Relevancy of variables used to classify farming system types*

In this study, we observed that the variables land size, herd size, land use activities and the contributions of activities to farm income and farming costs explained the diversity of farming system types, in line with literature (Daskalopoulou and Petrou, 2002; Guarín et al., 2020; Kuivanen et al., 2016; Ribeiro et al., 2021). However, hired labour and farm gross margin did not, though these were reported to be among key variables in farming systems research (Daskalopoulou and Petrou, 2002; Guarín et al., 2020; Kuivanen et al., 2016; Ribeiro et al., 2021; Ribeiro et al., 2021). Hired labour ratio was similar among farming system types because we analysed labour to assess whether the contribution of hired labour costs to the total labour costs differed between the types. This lack of differences was attributed to the fact that in type H, family labour was permanent and hired labour was casual, whereas in type M, hired labour was not required because the production scale was relatively small. Hence, we observed similarities in hired labour ratios between the types in this study. We deduce that our findings could hold true even if hired labour was expressed quantitively, as hired labour was permanent in resource-extensive types (CR and R) and was casual and periodic in resource-intensive types (H and M). Further, the use of both family and hired labour observed in this study is in line with literature about typologies of either farmers or farms or farming systems, though in literature the use of hired labour contributes to the observed diversity among the types (Alvarez et al., 2018; Daskalopoulou and Petrou, 2002; Guarín et al., 2020; Kuivanen et al., 2016).

In this study, we chose to use farm gross margin because farm income and farming costs differed between the types (e.g. due to variation in land use activities) and within types (due to variations on farm characteristics and resource endowments of farmers) (Alvarez et al., 2018; Guarín et al., 2020; Kuivanen et al., 2016; Zantsi et al., 2021). The issues discussed in this section show that relevant variables were used to develop a typology of farming systems in land reform farms of the study area. Hence, we concluded, given that this study focused on previously disadvantaged farmers, that each of the four identified farming system types is efficient in its own way.

4.3. *Drivers of farming system types*

The diversity of farming systems was reported to arise from, among others, biophysical, economic and socio-institutional variation which were often beyond the control of farming households (Alvarez et al., 2018; Chikowo et al., 2014; Guiomar et al., 2018; Köbrich et al., 2003; Senthilkumar et al., 2009; Tittonell et al., 2010). The farming system types observed in this study (i.e., CR, H, R and M) resulted from interactions among land reform policy models, capital endowments of farmers, physical capital endowments of farms and the market type for produce. Farms of type CR and R were present mostly under Rest, LRAD1 and PLAS policy models. Two attributes of these models influence the emergence of CR and R farm types. Firstly, the models transferred farms of relatively large sizes (Tables 4 and 7) which suited resource-extensive activities (i.e., rain fed crop and ruminants on natural grazing) (Netshipale et al., 2017; Ribeiro et al., 2021). Secondly, capital endowed farmers capable of owning ruminants benefited under these models. The ability of farmers in type CR and R to sell crops and ruminants in formal markets, meant cashflow was certain, a contribution to the emergence of these types as the demand for crop and ruminant products in informal markets was low. The large farm size required for CR and R meant these types of farms could only exist in peri-urban and rural locations, and their economic viability depended on produce being sold in formal markets, which were observed to be reliable than informal markets (Ferris et al., 2014; Guarín et al., 2020; ILUNRM, 2014). We attributed the presence of farming system type with mixed farming (CR), observed in farms of relatively large size, to two factors. Firstly, land reform policies gave farmers of type CR land which was previously used for crop plus ruminants. Secondly, farmers of type CR had interests on crop plus ruminants, hence they continued with these activities. Our findings suggest that mixed farming emerged in farms of large size and was intended to spread risk through diversification and was in line with literature (Culas and Mahendrarajah, 2005; Thornton and Herrero, 2015; Waha et al., 2018).

Where land reform policy models transferred farms of relatively small sizes (mostly under LRAD2) either with potential for horticulture farming (i.e., good soils and availability of water sources, (WDM (Waterberg District Municipality), 2014:85) or for monogastric farming, under intensive resource use, farming system type H and M emerged. In addition, capital endowed farmers with access to capital required for intensive land uses benefited the most from land reform policies (Netshipale et al., 2017) and post-settlement financial support was provided (DRDLR (Department of Rural Development and Land Reform), 2014:15). Literature also acknowledges the need for financial support, especially where resource-intensive activities are practiced by smallholders or in small farms (Guarín et al., 2020; Zantsi et al., 2021). The small farm size required for type H and M meant farms of these farming system types could exist in urban, peri-urban and rural locations. Farms of type H prevailed the most in peri-urban location because markets for farm inputs were often in urban centres and farmers sold produce in formal markets to ensure that farms were economically viable. Type M farms were in peri-urban and urban location because farm physical capital (number and capacity of production units) limited the scale of production, which meant production levels could not meet the demand in formal markets. Hence, type M farms could only exist (i.e., economically viable) next to locations where relatively large populations live (i.e., in peri-urban and urban locations) as produce were intended for informal markets. In line with our findings, Nesamvuni et al. (2016) reported that horticulture production is dependent on suitable natural capital (i.e., good soils and availability of water source), and availability of physical and financial capital.

We used literature on the biophysical conditions in the study area to make deductions regarding the influence of the interactions between these conditions and land reform policy models on the presence and emergence of farming system types. Literature declared the study area to be semi-arid with poor water sources (Nhemachena et al., 2011; WDM (Waterberg District Municipality), 2014:85). Land reform policy models were cognisant of the biophysical conditions as farms of relatively large sizes, which suited resource-extensive activities (i.e., rain fed crop and ruminants on natural grazing), were transferred under Rest, SLAG, LRAD1 and PLAS (Netshipale et al., 2017). It was this cognisance of the biophysical conditions by the policy models which led to irrigation being a key land use activity in fewer farms (28%: type H) compared to farms where it was not (72%: type CR, R and M combined). Ruminant farming is the most suited agricultural activity for semi-arid conditions (Boval et al., 2017; Mcdermott et al., 2010; WDM (Waterberg District Municipality), 2014); hence this was the key activity in 48% of the investigated farms. We attributed the low prevalence of type H farms (28%) to targeting of the economically disadvantaged section of the society by land reform policies, in addition to the biophysical conditions, but that of type M farms was solely due to the former (DLA (Department of Land Affairs),1997, 2006; MALA (Ministry for Agriculture and Land Affirs), 2001).

4.4. Implications for policy

This study's observation on how systems of type CR and M comprised both capital poor (under SLAG) and capital endowed (under Rest, LRAD1, LRAD2 and PLAS) farmers, indicates that farmers of all social classes use land reform farms (Aliber and Cousins, 2013; Netshipale et al., 2020). This study reveals that capital poor farmers of type CR and M depend on natural capital endowment (ruminant ownership) and availability of external capital support (DRDLR 2014:15). The findings of this study evident that there are no poor farmers in type H and R due to several factors. Firstly, they are not in type H due to their lack of physical and financial capital required for horticulture production.[5] Secondly, the poor benefited from land reform (only under SLAG) when the land grant was low (around US$3049/household) and the land price was around US$183/ha (Aliber and Cousins, 2013), hence the poor bought medium size farms (Netshipale et al., 2017). Lastly, the poor could not attain economic viability in type R farms as they owned fewer ruminants (Claessens et al., 2012; Gautam and Andersen, 2016; Netshipale et al., 2020). We deduced that poor farmers of type CR and M are the most in need of state support with physical and financial capital.

5. Conclusions

We used a mathematical classification approach to explore the diversity of farming system types and analysed the drivers of the diversity among such types in land reform farms of the Waterberg District of South Africa, using data collected through surveys and focus group discussions. The four identified farming system types were: crop plus ruminants–CR, horticulture–H, ruminants–R, and monogastric–M. Farming system types existed and emerged from the interactions among land reform policy models, capital endowments of farmers, physical capital endowments of farms, and type of produce market used, with biophysical conditions being entrenched on policy models. Horticulture was present where irrigation was possible and where not, crop, extensive ruminants and intensive monogastric existed. Ruminants were present where land reform policy models transferred farms of relatively large sizes, and horticulture and monogastrics were present where land reform policy models transferred farms of relatively small sizes with good infrastructure. Medium and large-scale production took place in farms where produce was sold in formal markets, and small-scale production took place in farms where produce was sold in informal markets. This study shows that capital endowed farmers are found in all four farming system types, and the lack of physical and financial capital by the poor restricts them to type CR and M.

Acknowledgements

We are grateful to farmers in Bela-Bela, Lephalale, Mogalakwena and Mookgopong local municipalities for their time and participation in the study. We thank the following colleagues: Mahlako K.T., Mikasi M.S. and Sebei J. Collaborations with Limpopo Department of Agriculture (LDA) and Department of Rural Development and Land reform are greatly appreciated. We also acknowledge and extend thanks to the Netherlands University Foundation for International Cooperation (NUFFIC, project NICHE/ZAF/012) and the University of Venda for funding this research. We would like to thank two anonymous reviewers and the editor for the comments and suggestions on earlier versions of this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2022.106116.

References

Adeola, A., et al., 2019. Rainfall trends and malaria occurrences in Limpopo Province, South Africa. Int. J. Environ. Res. Public Health 16 (24), 5156. https://doi.org/10.3390/ijerph16245156.
Aliber, M., Cousins, B., 2013. Livelihoods after land reform in South Africa. J. Agrar. Change 13 (1), 140–165. https://doi.org/10.1111/joac.12012.
Alvarez, S., et al., 2018. Capturing farm diversity with hypothesis-based typologies: an innovative methodological framework for farming system typology development. PLoS One 13 (5), 0194757. https://doi.org/10.1371/journal.pone.0194757.
Berre, D., et al., 2019. Different ways to cut a cake: comparing expert-based and statistical typologies to target sustainable intensification technologies, a case-study in Southern Ethiopia. Exp. Agric. 55 (S1), 191–207. https://doi.org/10.1017/S0014479716000727.
Bhattarai, S., et al., 2017. Combining farm typology and yield gap analysis to identify major variables limiting yields in the highland coffee systems of Llano Bonito, Costa Rica. Agric. Ecosyst. Environ. 243, 132–142. https://doi.org/10.1016/j.agee.2017.04.016.
Binswanger-Mkhize, H.P., 2014. From failure to success in South African land reform. Afr. J. Agric. Resour. Econ. 9 (4), 253–269 https://ageconsearch.umn.edu/record/197014.
Binswanger-Mkhize, H.P., Bourguignon, C., van den Brink, R., 2009. Introduction and summary. In: Binswanger-Mkhize, H.P., Bourguignon, C., van den Brink. Washington, R. (Eds.), Agricultural land redistribution: toward greater consensus. The World Bank, DC, pp. 3–42. https://doi.org/10.1596/978-0-8213-7627-0.
Boval, M., Angeon, V., Rudel, T., 2017. Tropical grasslands: a pivotal place for a more multi-functional agriculture. Ambio 46, 48–56. https://doi.org/10.1007/s13280-016-0806-5.
Chambers, R., 1981. Rapid rural appraisal: rationale and repertoire. Public Admin. Dev. 1, 95–104. https://doi.org/10.1002/pad.4230010202.
Chikowo, R., Zingore, S., Snapp, S., Johnston, A., 2014. Farm typologies, soil fertility variability and nutrient management in smallholder farming in Sub-Saharan Africa. Nutr. Cycl. Agroecosyst. 100 (1), 1–18. https://doi.org/10.1007/s10705-014-9632-y.
Claessens, L., et al., 2012. A method for evaluating climate change adaptation strategies for small-scale farmers using survey, experimental and modeled data. Agric. Syst. 111, 85–95. https://doi.org/10.1016/j.agsy.2012.05.003.
Constatini, P., Linting, M., Porzio, G.C., 2010. Mining performance data through nonlinear PCA with optimal scaling. Appl. Stoch. Models Bus. Ind. 26, 85–101. https://doi.org/10.1002/asmb.771.
Cortez-Arriola, J., et al., 2015. Leverages for on-farm innovation from farm typologies? An illustration for family-based dairy farms in North-West Michoacán, Mexico. Agric. Syst. 135, 66–76. https://doi.org/10.1016/j.agsy.2014.12.005.
Cousins, B., 2013. Smallholder irrigation schemes, agrarian reform and 'accumulation from above and from below' in South Africa. J. Agrar. Change 13 (1), 116–139. https://doi.org/10.1111/joac.12000.
Culas, R.J., Mahendrarajah, M.S., 2005. Causes of diversification in agriculture over time: evidence from norwegian farming sector. In: 11th Congress of the EAAE (European Association of Agricultural Economists), "The Future of Rural Europe in the Global Agri-Food System", August 24–27. Copenhagen, Denmark. 〈https://core.ac.uk/display/7034548〉.
Daskalopoulou, I., Petrou, A., 2002. Utilising a farm typology to identify potential adopters of alternative farming activities in Greek agriculture. J. Rural Stud. 18 (1), 95–103. https://doi.org/10.1016/S0743-0167(01)00027-4.
DEA (Department of Environmental Affairs), 2013. Climate Trends and Scenarios for South Africa. 〈https://www.environment.gov.za/sites/default/files/docs/climate_trends_bookV3.pdf〉, (Assessed February, 2020).
Dixon, J.,Gulliver, A., Gibbon, D., Hall, M., 2001. Summary–Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World (English). World Bank Group, Washington, DC. 〈www.fao.org/3/a-ac349e.pdf〉.
DLA (Department of Land Affairs), 1997. White Paper on South African Land Policy. LDA, Pretoria.
DLA (Department of Land Affairs), 2006. Implementation Plan for the Proactive Land Acquisition Strategy. LDA, Pretoria.

[5] https://www.javatpoint.com/intensive-farming-vs-extensive-farming Accessed September, 2018.

DAFF (Department of Agriculture, Forestry and Fisheries), 2015. Trends in theagricultural sector 2014. (http://www2.senwes.co.za/Files/main_productsservices/agriservices/2015/Trends2014.pdf), (AccessedJune, 2016).
DAFF(Department of Agriculture, Forestry and Fisheries), 2016. Trends in theagricultural sector 2016. (http://www.daff.gov.za/Daffweb3/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/.Trends%20in%20the%20Agricultural%20Sector%202016.pdf), (Accessed July, 2017).
DoA (Department of Agriculture), 2008. Vegetable production in a nutshell. (http://www.nda.agric.za/docs/infopaks/vegprodnutshell.pdf), (AccessedJune, 2016).
DAFF(Department of Agriculture, Forestry and Fisheries) 2012. Abstract ofagricultural statistics, 2012. (http://www.nda.agric.za/docs/statsinfo/Abstract_2012.pdf), (Accessed June, 2016).
DOL (Department of Labour), 2014. Basic Conditions of Employment Amendment Act, Act No. 20 0f 2013. RSA: Government Gazette Vol. 590 No. 37955.
Domínguez-Rodrigo, M., de Juana, S., Galán, A.B., Rodríguez, M., 2009. A new protocol to differentiate trampling marks from butchery cut marks. J. Archaeol. Sci. 36 (12), 2643–2654. https://doi.org/10.1016/j.jas.2009.07.017.
Dossa, L.H., et al., 2011. Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: an attempt towards a regional typology. Landsc. Urban Plan. 102 (3), 197–206. https://doi.org/10.1016/j.landurbplan.2011.04.005.
DRDLR (Department of Rural Development and Land Reform), 2014. End of Term Report 2009–2014. DRDLR, Pretoria. Pretoria.
DRDLR (Department of Rural Development and Land Reform) , n.d. Audit of Restituted Land as at March 2009 (Including Those from RLCC Database but Exclude Non Agricultural Properties) and Land Reform Database-LRAD for Limpopo Province. Unpublished data.
Eisenack, K., et al., 2019. Design and quality criteria for archetype analysis. Ecol. Soc. 24 (3), 6. https://doi.org/10.5751/ES-10855-240306.
Emtage, N., Herbohn, J., Harrison, S., 2006. Landholder typologies used in the development of natural resource management programs in Australia–a review. Australas. J. Environ. Manag. 13 (2), 79–94. https://doi.org/10.1080/14486563.2006.9725119.
Ferris, S. et al. 2014. Linking Smallholder Farmers to Markets and the Implications for Extension and Advisory Services. 〈https://www.agrilinks.org/sites/default/files/resource/files/MEAS_Discussion_Paper_4_-_Linking_Farmers_To_Markets_-_May_2014.pdf〉, (Accessed March 2020).
Garrity, D.,Dixon, J., Boffa, J.M., 2012. Understanding African farming systems: science and policy implications. In: Food Security in Africa: Bridging Research and Practice. 〈http://aciar.gov.au/aifsc/sites/default/files/images/understanding_african_farming_systems_report_for_aifsc_conference.pdf〉, (Accessed May 2018).
Gautam, Y., Andersen, P., 2016. Rural livelihood diversification and household well-being: insights from Humla, Nepal. J. Rural Stud. 44, 239–249. https://doi.org/10.1016/j.jrurstud.2016.02.001.
GCIS (Government Communication and Information System), 2018. South Africa Yearbook 2017/18: Agriculture. 〈https://www.gcis.gov.za/sites/default/files/docs/resourcecentre/yearbook/3-Agriculture2018.pdf〉, (Accessed June 2019).
Gelbard, R., Goldman, O., Spiegler, I., 2007. Investigating diversity of clustering methods: an empirical comparison. Data Knowl. Eng. 63 (1), 155–166. https://doi.org/10.1016/j.datak.2007.01.002.
Giller, K.E., 2013. Can we define the term 'farming systems'? A question of scale. Outlook Agric. 42 (3), 149–153. https://doi.org/10.5367/oa.2013.0139.
Graskemper, V., Yu, X., Feil, J.H., 2021. Farmer typology and implications for policy design – an unsupervised machine learning approach. Land Use Policy 103, 10532. https://doi.org/10.1016/j.landusepol.2021.105328.
Guarín, A., et al., 2020. A New Typology of Small Farms in Europe. Glob. Food Secur. 26, 100389 https://doi.org/10.1016/j.gfs.2020.100389.
Guiomar, N., et al., 2018. Typology and distribution of small farms in Europe: towards a better picture. Land Use Policy 75, 784–798. https://doi.org/10.1016/j.landusepol.2018.04.012.
HarvestChoice/IFPRI, 2011. Harvestchoice 2005 Total Livestock Population (TLU) Data. 〈http://harvestchoice.org/data/total-livestock-population-tlu-2005〉, (Accessed March 2016).
IBM Corp. Released, 2019. IBM SPSS Statistics for Windows, Version 26. IBM Corp, Armonk, New York.
ILUNRM, 2014. Factors Influencing Small- Scale Farmers' Choice of Formal or Informal Raw Milk Markets. 〈https://sluse.dk/project/kenya_factors_influencing_small-scale_farmers_choice_of_formal_or_informal_raw_milk_markets.pdf〉, (Accessed September 2021).
Jain, R., Koronios, A., 2008. Innovation in the cluster validating techniques. Fuzzy Optim. Decis. Mak. 7 (3), 233–241. https://doi.org/10.1007/s10700-008-9033-2.
Johannesburg Market, 2016. Daily prices on 13 June 2016. (http://www.joburgmarket.co.za/dailyprices.php), (Accessed June, 2016).
Kaufman, L., Rousseuw, P.J., 1990. Biometrics Finding Groups in Data: An Introduction to Cluster Analysis. John Wiley and Sons Inc, Chinchester, New York, Weinheim (ISBN: 978-0-471-73578-6).
Kepe, T., Hall, R., 2016. Land Redistribution in South Africa. 〈https://www.parliament.gov.za/storage/app/media/Pages/2017/october/High_Level_Panel/Commissioned_Report_land/Commissioned_Report_on_Land_Redistribution_Kepe_and_Hall.pdf〉, (Accessed June 2020).
Keswell, M., Carter, M., 2014. Poverty and land redistribution. J. Dev. Econ. 110, 250–261. https://doi.org/10.1016/j.jdeveco.2013.10.003.
Köbrich, C., Rehman, T., Khan, M., 2003. Typification of farming systems for constructing representative farm models: two illustrations of the application of multi-variate analyses in Chile and Pakistan. Agric. Syst. 76, 141–157. https://doi.org/10.1016/S0308-521X(02)00013-6.
Kok, M., et al., 2016. A new method for analysing socio-ecological patterns of vulnerability. Reg. Environ. Change 16 (1), 229–243. https://doi.org/10.1007/s10113-014-0746-1.
Kostov, P., McErlean, S., 2006. Using the mixtures-of-distributions technique for the classification of farms into representative farms. Agric. Syst. 88 (2–3), 528–537. https://doi.org/10.1016/j.agsy.2005.07.007.
Kostrowicki, J., 1977. Agricultural typology concept and method. Agric. Syst. 2 (1), 33–45. https://doi.org/10.1016/0308-521X(77)90015-4.
Kuivanen, K.S., et al., 2016. Characterising the diversity of smallholder farming systems and their constraints and opportunities for innovation: a case study from the Northern Region, Ghana. NJAS - Wagening. J. Life Sci. 78, 153–166. https://doi.org/10.1016/j.njas.2016.04.003.
Lahiff, E., 2007. Business Models in Land Reform. Research Report No. 27, Programme for Land and Agrarian Studies, University of the Western Cape.
LDRT (Limpopo Deprtment of Road and Transport), 2012. Limpopo Province Freight Data Bank > Authorities > Waterberg. 〈http://www.ldrt.gov.za/LPFDB/authorities-waterberg.html〉 (Accessed December 2012).
M'Marete, C.K., 2003. Climate and water resources in the Limpopo Province. In: Nesamvuni, A.E., Oni, S.A., Odhiambo, J.J.O., Nthakheni, N.D. (Eds.), Agriculture as the cornerstone of the economy of the Limpopo Province. Livhu's Printing Enterprises cc, Johannesburg.
MALA (Ministry for Agriculture and Land Affirs), 2001. Land Redistribution for Agricultural Development: A Sub-Programme of the Land Redistribution Programme. MALA, Pretoria.
Mcdermott, J.J., et al., 2010. Sustaining intensification of smallholder livestock systems in the tropics. Livest. Sci. 130, 95–109. https://doi.org/10.1016/j.livsci.2010.02.014.
Migose, S.A., Bebe, B.O., de Boer, I.J.M., Oosting, S.J., 2018. Influence of distance to urban markets on smallholder dairy farming systems in Kenya. Trop. Anim. Health Prod. 50, 1417–1426. https://doi.org/10.1007/s11250-018-1575-x.
Nemecek, T., et al., 2011. Life cycle assessment of Swiss farming systems: II. Extensive and intensive production. Agric. Syst. 104 (3), 233–245. https://doi.org/10.1016/j.agsy.2010.07.007.
Nesamvuni, A.E., Mpandeli, N.S., Tshikolomo, K.A., Kgowedi, C., 2016. The enabling geophysical agricultural environment for agriculture in Gauteng, South Africa. J. Hum. Ecol. 54 (1), 59–69. https://doi.org/10.1080/09709274.2016.11906987.
Netshipale, A.J., et al., 2017. Land reform in South Africa: beneficiary participation and impact on land use in the Waterberg District. NJAS - Wagening. J. Life Sci. 83, 57–66. https://doi.org/10.1016/j.njas.2017.07.003.
Netshipale, A.J., et al., 2020. Agriculture in land reform farms: impact on livelihoods of beneficiaries in the Waterberg District, South Africa. Land Use Policy 97, 104710. https://doi.org/10.1016/j.landusepol.2020.104710.
Nhemachena, C., Chakwizira, J., Mashiri, M., Dube, S., 2011. A policy framework for sustainable utilisation of farmland for the Waterberg District municipality in South Africa. In: Behnassi, M., Shahid, S.A., D'Silva, J. (Eds.), Sustainable Agricultural Development: Recent Approaches in Resources Management and Environmentally-Balanced Production Enhancement. Springer, Dordrecht Heidelberg London New York, pp. 99–114 (e-ISBN 978-94-007-0519-7).
Oberlack, C., et al., 2016. Sustainable livelihoods in the global land rush? Archetypes of livelihood vulnerability and sustainability potentials. Glob. Environ. Change 41, 153–171. https://doi.org/10.1016/j.gloenvcha.2016.10.001.
Olén, B.N., et al., 2021. Effects of farm type on food production, landscape openness, grassland biodiversity, and greenhouse gas emissions in mixed agricultural-forestry regions. Agric. Syst. 189, 10307. https://doi.org/10.1016/j.agsy.2021.103071.
Oosting, S., Udo, H.M.J., Viets, T.C., 2014. Development of livestock production in the tropics: farm and farmers' perspectives. Animal 8 (8), 1238–1248. https://doi.org/10.1017/S1751731114000548.
Paas, W., Groot, J.C.J., 2017. Creating adaptive farm typologies using Naive Bayesian classification. Inf. Process. Agric. 4, 220–227. https://doi.org/10.1016/j.inpa.2017.05.005.
Pituch, K.A., Stevens, J.P., 2016. Routledge Applied Multivariate Statistics for the Social Sciences, 6th ed. Routledge, New York/Oxon. e-ISBN: 9781317805915.
Ribeiro, P.P.C.F., et al., 2021. Explaining farming systems spatial patterns: a farm-level choice model based on socioeconomic and biophysical drivers. Agric. Syst. 191, 10314. https://doi.org/10.1016/j.agsy.2021.103140.
Rousseeuw, P.J., 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. J. Comput. Appl. Math. 20, 53–65. https://doi.org/10.1016/0377-0427(87)90125-7.
SEAMEO (Southeast Asian Ministers of Education Organisation), 2000. Land Reform – Basics Main Elements 2. 〈http://www.seameo.org/vl/landreform/ir2.htm〉, (Accessed October 2012).
Senthilkumar, K. , et al., 2009. Characterising rice-based farming systems to identify opportunities for adopting water efficient cultivation methods in Tamil Nadu, India. Agric. Water Manag. vol. 96(12), pp. 1851–60. 〈https://doi.org/10.1016/j.agwat.2009.08.007〉.
Sietz, D., Choque, S.E.M., Lüdeke, M.K.B., 2012. Typical patterns of smallholder vulnerability to weather extremes with regard to food security in the Peruvian Altiplano. Reg. Environ. Change 12, 489–505. https://doi.org/10.1007/s10113-011-0246-5.
Thornton, P.K., Herrero, M., 2015. Adapting to climate change in the mixed crop and livestock farming systems in Sub-Saharan Africa. Nat. Clim. Change 5, 830–836. https://doi.org/10.1038/nclimate2754.
Tittonell, P., et al., 2005. Exploring diversity in soil fertility management of smallholder farms in Western Kenya: I. Heterogeneity at region and farm scale. Agric. Ecosyst. Environ. 110, 149–165. https://doi.org/10.1016/j.agee.2005.04.001.

Tittonell, P., et al., 2010. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – a typology of smallholder farms. Agric. Syst. 103 (2), 83–97. https://doi.org/10.1016/j.agsy.2009.10.001.
Tittonell, P., et al., 2020. Functional farm household typologies through archetypal responses to disturbances. Agric. Syst. 178, 10271. https://doi.org/10.1016/j.agsy.2019.102714.
Václavík, T., Lautenbach, S., Kuemmerle, T., Seppelt, R., 2013. Mapping global land system archetypes. Glob. Environ. Change 23, 1637–1647. https://doi.org/10.1016/j.gloenvcha.2013.09.004.
Valente, C., 2011. Household returns to land transfers in South Africa: a Q-squared analysis. J. Dev. Stud. 47 (2), 354–376. https://doi.org/10.1080/00220380903428415.
Waha, K., et al., 2018. Agricultural diversification as an important strategy for achieving food security in Africa. Glob. Change Biol. 24, 3390–3400. https://doi.org/10.1111/gcb.14158.
WDM (Waterberg District Municipality), 2005. Agricultural Development Strategy: Status Quo, Policy Analysis and Opportunity Identification (Draft for Discussion). WDM, Modimolle.
WDM (Waterberg District Municipality), 2014. Waterberg District Municipality 2014/15 IDP. WDM, Modimolle.
Wegerif, Marc, 2004. A Critical Appraisal of South Africa's Market-Based Land Reform Policy: The Case of the Land Redistribution for Agricultural Development (LRAD) Programme in Limpopo (Research Report No. 19). Programme for Land and Agrarian Studies, University of the Western Cape.
World Bank, 1975. Land Reform (English). Sector Policy Paper. The World Bank, Washington, DC.
Zantsi, S., Pienaar, L.P., Greyling, J.C., 2021. A typology of emerging farmers in three rural provinces of South Africa: what are the implications for the land redistribution policy? Int. J. Soc. Econ. 48 (5), 724–747. https://doi.org/10.1108/IJSE-10-2020-0728.