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Research Paper

Learning from positive deviants' practices to improve the performance of mixed crop-livestock systems in Zimbabwe

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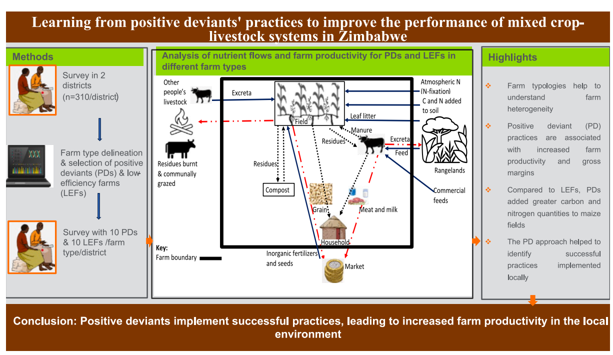
HIGHLIGHTS

- Farm typologies help to understand farm heterogeneity.
- Positive deviant (PD) practices are associated with increased farm productivity.
- Compared to low-efficiency farms (LEFs), PDs added greater carbon and nitrogen quantities to maize fields.
- The PD approach helped to identify successful practices implemented locally.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: In Zimbabwe, farm productivity of smallholder farmers practising mixed crop-livestock farming is hindered by climate variability, inadequate nutritious feeds, poor soil fertility, and resource trade-offs. Despite these challenges, positive deviants (PDs) within these communities achieve better outcomes using resources similar to those of other farmers.
OBJECTIVE: This study sought to identify crop-livestock practices that enable PDs to outperform low-efficiency farms (LEFs) and to compare their farm productivity (energy output), nutrient quantities added to croplands, gross margins and return on investment (ROI) from crop production.
METHODS: Data from a survey conducted in Mutoko and Buhera districts of Zimbabwe in 2021 were used to derive a farm typology per district and identify PDs and LEFs within farm types. Selected farms were subjected to detailed surveys to identify their specific practices.
RESULTS AND CONCLUSIONS: Compared to LEFs, PD farmers achieved significantly greater crop productivity — by 86 %, 89 % and 28 % — and livestock productivity — by 156 %, 101 % and 136 % on better-off, average and

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poorly-resourced farms, respectively. PDs had larger cropping areas (on average 42 % more) and owned more livestock (39 % more TLUs) than LEFs, but this does not fully explain differences in productivity.
PDs used more inputs (fertilizer, labour and others) for crop production than LEFs and added more carbon and nitrogen to their soils. In both districts, PDs consistently outperformed LEFs in gross margins and ROI. The differences in economic performance between PDs and LEFs were more pronounced among the better-off farmers.
Key practices contributing to PDs' success included recommended fertilizer use, timely operations, livestock supplementary feeding, fodder production, and adherence to extension advice. Financial shortages for the purchase of seeds, fertilizers, and veterinary drugs and poor access to information are potential hindrances to the adoption of PD practices by LEF farmers.
SIGNIFICANCE: The combination of a farm typology and the PD approach helped to tailor recommendations to farms differing in resource-endowment, based on successful practices implemented in the region.

1. Introduction

In Zimbabwe, the predominant farming system among smallholders involves mixed crop-livestock production (Baudron et al., 2024). A farming system can be conceptualized as an organized combination of production factors and activities geared towards agricultural production and directed for self-subsistence and sale (Diepart and Allaverdian, 2018). In mixed crop-livestock systems, farmers engage in crop cultivation and livestock rearing within a single farming unit and are characterized by intentional interactions between the two enterprises (Sekaran et al., 2021). The benefits of mixed crop-livestock systems may include enhanced nutrient cycling, risk mitigation, improved soil health, increased farm income, enhanced resilience to climate change, reduced pests and diseases, efficient resource use, cultural and traditional significance, and improved food security (Descheemaeker et al., 2016; Sekaran et al., 2021; Seo, 2010; Thornton and Herrero, 2001).

The intensification of crop production in Africa is generally constrained by poor soil fertility, climate variability, high cost of inputs versus low value of outputs, biotic constraints, labour constraints, and trade-offs in resource allocation (Bonilla-Cedrez et al., 2021; Kindu et al., 2014; Langyintuo, 2020). Crop production in semi-arid Zimbabwe is dominated by cereal and legume production. Major cereals are maize (*Zea mays*), the staple crop of Zimbabwe, and small grains such as sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*). Common grain legumes include common bean (*Phaseolus vulgaris*), groundnuts (*Arachis hypogaea*), bambara nut (*Vigna subterranea*), and cowpea (*Vigna unguiculata*) (ZimVAC, 2022).

Cattle, goats, poultry, sheep, donkeys, and pigs dominate livestock rearing on smallholder farms in Zimbabwe. Livestock represents a form of savings and investment, and a source of security, meat, and milk (Descheemaeker et al., 2018). Livestock also contributes to crop production by providing draught power and manure (Homann-Kee et al., 2015; Mutsamba-Magwaza et al., 2022). To understand the interactions between crop and livestock components, it is essential to have a holistic understanding of the entire farming system. Due to the diversity among mixed farms, it is crucial to categorize farmers into farm types (Berre et al., 2019; Mkuhlani et al., 2020). This approach helps to avoid blanket recommendations and allows an understanding of farmers' current practices, specific needs, and potential strategies (Chikowo et al., 2014; Hassall et al., 2023; Nyambo et al., 2019). A farm typology serves as a classification of farming systems, distinguishing them based on attributes such as production objectives, geographic locations, socioeconomic status as well as ownership, and technical and structural characteristics (Diepart and Allaverdian, 2018; Dunjana et al., 2018).

Since smallholder farm types differ in resource endowment (Dunjana et al., 2018), resource and nutrient flows within these farms are likely to differ (Ncube et al., 2009). Quantifying soil fertility amendments across farm types provides an estimate of nutrient applications, which in turn influences crop productivity (Nyamangara et al., 2009). Maintenance of soil fertility is important to sustain productivity on smallholder farms (Rusinamhodzi et al., 2016), given that current crop yields in Zimbabwe are well below potential yields (Bonilla-Cedrez et al., 2021; FAO and DWFI, 2015). Moreover, partial nutrient balances of the most limiting nutrients in crop production – i.e., nitrogen (N), phosphorus (P) and potassium (K) – serve as indicators of farm sustainability and productivity (Nyamasoka-Magonziwa et al., 2023; Rufino et al., 2006).

Within farm types, different categories of performers tend to exist, such as positive deviants (above-average performers), average performers, and below-average performers (low-efficiency farms) with respect to crop and livestock productivity. Positive deviant farmers (PDs) are individuals who, despite facing similar resource endowments and constraints as their counterparts, exhibit above-average performance due to their innovative use of available assets, inputs, and processes, known as positive deviant practices (Marsh et al., 2004; Pant and Odame, 2009; Toorop et al., 2020). Identifying positive deviant practices could be useful in developing realistic interventions that benefit farms within a specific farm type and environment.

However, there is limited knowledge of the positive deviant practices implemented in Zimbabwe that could enhance farm productivity and sustainability. Understanding these practices could inform targeted interventions for improving agricultural outcomes in these environments. Against this background, this study sought to assess smallholder farmers' crop and livestock PD practices in Zimbabwe's semi-arid environments. The study aimed to answer the following research questions:

1. What specific crop-livestock management practices enable positive deviants (PDs) to outperform fellow smallholder farmers in the same farm type and agroecological environment?
2. How do carbon and nitrogen net inputs to the soil and partial nitrogen balances differ between positive deviants and low-efficiency farms within farm types?
3. How do energy outputs (a proxy of productivity) from crop and livestock systems differ between positive deviant and low-efficiency farms within same farm types?
4. What are the differences in gross margins and return on investment (ROI) between PDs and LEFs within farm types, based on their crop production practices?

2. Materials and methods

2.1. Study sites

The study was conducted in Zimbabwe's Mutoko and Buhera districts from February to December 2021 and in May 2024. Mutoko district is located in Mashonaland East Province, in the north-eastern part of Zimbabwe. The district is bounded by coordinates ranging from 17° 07′ 30" S to 17° 34' 30" S and 32° 15′ 00" E to 32° 39' 00" E", at an altitude range of 850 to 1500 m.a.s.l. Buhera district, situated within Manicaland Province in eastern Zimbabwe, is bounded by coordinates ranging from 19° 00′ 00" S to 19° 50' 00" S and from 32° 30′ 00" E to 31° 50' 00" E, at an altitude range of 450 to 1700 m.a.s.l. The study was conducted in Natural Regions (NR) IV sections of both districts. In NR IV, annual rainfall ranges from 450 to 650 mm, while mean annual temperatures range from 18 °C to 24 °C (Mugandani et al., 2012).

2.2. Delineation of farm types and selection of positive deviants and low-efficiency farms

A survey was administered to 310 households per district in Mutoko and Buhera districts. The data were used to statistically delineate farm types for each district using a combination of Principal Coordinate Analysis (PCO) and hierarchical tree clustering (HCA) following Hassall et al. (2023). PCO was used to reduce the dimensionality of the data set before delineating clusters through HCA. Variables used to calculate dissimilarities included:

1) Continuous structural variables: age of the household head (HhH), family size (n), cropped area (ha), the value of equipment owned (USD), and cattle and small ruminants owned (Tropical Livestock Units - TLU). TLU represents an animal of 250 kg, with small ruminants, pigs, donkeys, and cattle equivalent to 0.1, 0.2, 0.5, and 0.7 TLU, respectively (Jahnke, 1982).
2) Continuous functional variables: total grain harvested in the 2019/20 season (kg), quantities of fertilizers and organic amendments used in the 2019/20 season (kg), and livestock sold and slaughtered (TLU).
3) Binary structural variables including the gender of the HhH (male vs female), education level of the HhH (no education or primary level vs above secondary level or more), whether the household received financial help from relatives (yes vs no), whether the household had external financial dependents (yes vs no), whether it hired labor (yes vs no) and whether it sold labor (yes vs no).
4) Binary/factorial functional variables, including the primary source of income (crop sales vs livestock sales vs casual labour and others), own food production as the primary source of food (yes vs no), and consumption of animal products in the past 24 h preceding the survey (yes vs no).
5) Binary variables of adoption of crop practices (yes vs no): certified seeds, seed banks, drought tolerant (DT) varieties, small grains, crop rotation, intercropping, cover crops, mulching, integrated pest management, compost/manure, irrigation, and optimum plant densities.
6) Binary variables of adoption of livestock practices (yes vs no): improved livestock, shelters, water infrastructure, routine vaccination, home vaccination, castration, deworming, dipping, home spraying, home feeding, fodder production, fodder preservation, commercial feeding, artificial insemination, and pen fattening.

Separate distance matrices were computed for these six groups of variables and later combined using weighted averages proportional to the number of variables in each matrix. The combined matrix was subjected to principal coordinates analysis to identify dimensions that captured maximum distances. Subsequently, hierarchical cluster analysis (HCA) was conducted on these dimensions to delineate clusters/farm types. A random forest classification model was run to identify variables that segregated farm types the most in each district. For that, farm type was used as the dependent variable, and all variables used to delineate the farm typologies were used as predictors.

Following the delineation of farm types, 10 positive deviants (PDs) and 10 low-efficiency farms (LEFs) were identified within each farm type using data envelopment analysis (DEA). For that, cropped area (ha) and total livestock owned (TLU) were used as input variables, and total cereal grain production (kg) during the 2019/20 agricultural season and livestock offtake (TLU) were used as output variables. The livestock offtake rate (expressed in Tropical Livestock Units, TLU) was calculated from livestock sold and slaughtered, while total livestock ownership included livestock owned at the end of the reference period, as well as livestock slaughtered, sold, and deaths during the reference period.

In each farm type, PDs were selected as the ten farms with the highest efficiency (derived from DEA) and LEFs as the ten farms with the lowest efficiency per district. The list of PDs and LEFs selected through DEA was subsequently validated in collaboration with local, ward-based agricultural extension officers. Farms which were not categorised as PDs or LEFs in a farm type are referred to as middle-performing farms.

2.3. Data collection methods to characterize positive deviants and identify their practices

From the DEA-generated lists of 10 PDs and 10 LEFs, 8 of each group were randomly selected within each farm type and district to participate in a survey in November 2021, aimed at identifying positive deviant practices, resulting in a total sample of 96 households from both Mutoko and Buhera districts. The farm household survey was conducted using KoBotoolbox (https://www.kobotoolbox.org/). The survey captured information on crops, inputs, residue use, milk production, cattle condition, feed composition throughout the year, income and expenses, food sources and security status, as well as driving factors and constraints to crop and livestock production. The physical condition of cattle during different seasons of the year was inferred from images depicting fat, medium, or lean cattle. Farmers selected the picture that best resembled their cattle's condition during the different seasons. During the survey, PDs from better-off and poorly-resourced farms in Buhera, as well as better-off and average farms in Mutoko, were asked to list practices they considered PD practices. In May 2024, the adoption of the suggested PD practices was enquired from both PDs and LEFs across all farm types. Additional PD practices were recorded from PDs through a free listing.

2.4. Data handling

2.4.1. Nutrient flows

To understand how PDs and LEFs manage resources, net carbon (C) and nitrogen (N) inputs added to maize fields and a partial N balance were estimated for each of the 96 farms participating in the second survey. The quantities of C and N (kg/ha) added to the soil were estimated from survey data by summing up the amounts of C and N in both organic and inorganic inputs added to maize fields. Maize fields were chosen since smallholder farmers in Zimbabwe apply a substantial proportion of fertilizers to maize (Bore, 2019).

The partial N balance was calculated as the difference between the total annual imports and exports at farm level (Chavarría et al., 2018; Rimhanen and Kahiluoto, 2014). Nitrogen imports included nitrogen fixation by legume crops, inorganic fertilizers, imported feeds, livestock, mulch materials, and livestock excreta deposited on farm fields by other people's livestock during communal grazing of crop residues. Sources of N exports included crop residues grazed by other people's livestock or burnt and harvested grain, milk, and meat (Fig. 1). The partial N balance calculations excluded nutrient imports through deposition and exports through leaching, erosion, and gaseous forms. Nitrogen imported through biological nitrogen fixation was calculated based on reported above-ground biomass yields of groundnut and cowpea. The estimated nitrogen derived from the air (%NdfA) for groundnuts and cowpeas was calculated as 44 % and 57 %, respectively, of total nitrogen in the harvested biomass, as reviewed by Franke et al. (2018).

The quantity of manure produced by farmers' own livestock was calculated using an estimated 3.3 kg dry manure/day/TLU (Haileslassie et al., 2006). From the total manure produced per TLU, it was estimated that 40 % is deposited off-farm in communal grazing areas, while the remaining 60 % is deposited on-farm (Rimhanen and Kahiluoto, 2014). Livestock excreta deposited on farm fields by other people's livestock whilst grazing crop residues were estimated according to Koelsch (2006).

The C and N concentrations of crop residues, organic fertilizers, crop and livestock outputs, and other livestock feeds were based on values and references reported in supplementary material (SM Table 1).

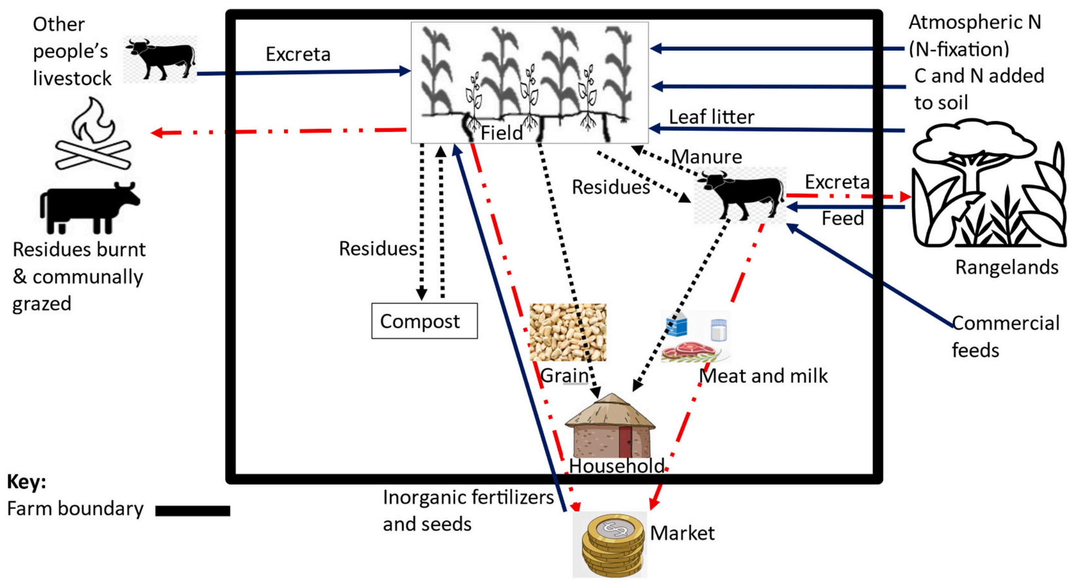

Fig. 1. Overview of nutrient flows in smallholder farming systems of Zimbabwe.

Table 1
Characteristics of farm types in Mutoko and Buhera districts during the 2019/20 season. The number in brackets represents the standard deviation of the mean.

	Mutoko			Buhera		
Characteristic	Better-off farms N = 139	Average farms N = 78	Poorly-resourced farms N = 91	Better-off farms N = 82	Average farms N = 72	Poorly-resourced farms N = 142
Female-headed households	32 % a	32 % a	66 % b	12 % a	38 % b	44 % b
Hiring labor	47 %	27 %	21 %	13 %	4.4 %	9.0 %
Selling labor	37 %	26 %	59 %	26 %	64 %	77 %
Education (higher than primary)	55 % a	54 % a	45 % b	68 % a	57 % b	58 % b
Household size (n)	5.9 (3.4) a	5.0 (3.3) ab	4.5 (3.0) b	6.9 (3.7) a	6.5 (4.1) a	6.6 (3.8) a
Total cropped area (ha)	1.52 (1.67) a	1.04 (1.57) b	1.11 (1.79) b	2.84 (4.11) a	2.58 (3.08) a	1.52 (1.64) b
Proportion of non-cereal crop	0.41 (0.19) a	0.37 (0.21) b	0.33 (0.22) c	0.34 (0.17) a	0.34 (0.20) a	0.28 (0.18) b
Cereal production in 2019/20 (kg)	594 (661) a	245 (233) b	158 (145) c	471 (650) a	241 (223) b	137 (209) c
Cattle (n)	5.8 (4.1) a	3.4 (4.0) b	1.2 (2.1) c	5.2 (4.8) a	5.5 (11.5) a	1.0 (2.3) b
Goats and sheep (n)	5.5 (4.1) a	4.0 (4.0) b	2.6 (2.4) c	6.3 (6.0) a	5.4 (5.4) b	3.1 (5.7) c
Poultry (n)	11.8 (11.6) a	8.2 (6.9) b	3.3 (3.0) c	16.9 (21.1) a	13.2 (17.3) b	8.5 (8.0) c
Livestock sold (TLU/year)	0.33 (0.75) a	0.42 (2.57) b	0.05 (0.23) c	0.33 (1.4) a	0.21 (0.62) b	0.10 (0.54) c
Fertilizer applied (kg)	169 (108) a	119 (72) b	91 (72) c	148 (129) a	97 (75) b	79 (76) c
Organic amendment (kg)	1382 (1560) a	463 (431) b	381 (693) c	1189 (1486) a	816 (1925) b	440 (667) c
Equipment value (US$)	441 (318) a	273 (287) b	87 (154) c	519 (292) a	388 (291) b	219 (250) c
Livestock as the main source of income (%Hh)	3.6 % a	12 % b	2.2 % a	17.0 % a	2.8 % b	3.5 % b
Crop as the main source of income (%Hh)	80 % a	55 % b	49 % b	71 % a	44 % b	52 % c
Off-farm activities as main source of income (%Hh)	17 % a	33 % b	48 % c	12 % a	53 % b	44 % c

Where Hh refers to households, TLU to tropical livestock units, and US$ to United States dollars. Significance levels were set at $P \leq 0.05$.

2.4.2. Farm productivity

Farm productivity was quantified through annual crop and livestock gross energy outputs (KJ). This method allowed the evaluation of contributions from different farm activities to the energy output, thus providing an indication of food and nutrition security in the different farm types (Sekaran et al., 2021).

The gross energy contents for milk, meat, harvested grain, and crop residues used are shown in SM Table 2. Meat production was estimated from livestock sold and slaughtered over a year. Information on quantities of grain produced over a year was obtained from the survey. The quantity of residues produced per farm was estimated from the quantities of grain produced using harvest indices of respective crops (Mtambanengwe and Mapfumo, 2006; Ncube, 2007).

2.4.3. Gross margins and return on investment

Gross margins were calculated to determine the profitability of cropping systems implemented by PDs and LEFs across farm types using the formula:

Table 2
P-values from a t-test comparing the mean efficiency of positive deviants (PDs), low-efficiency farms (LEFs) and middle-performing farms within each farm type. Efficiency here refers to partial farm-level efficiency obtained from data envelop analysis, using cultivated area and livestock ownership as input, and total grain production and livestock offtake as output.

Farm Type	Performance level	Buhera	Mutoko
Better-off	PDs vs middle performers	<0.001	<0.001
	PDs vs LEFs	0.005	0.034
	LEFs vs middle performers	0.016	0.045
Average	PDs vs middle performers	0.017	<0.001
	PDs vs LEFs	0.039	0.015
	LEFs vs middle performers	ns	0.041
	PDs vs middle performers	0.039	0.013
	PDs vs LEFs	0.046	0.03
Poorly-resourced	LEFs vs middle performers	ns	0.048

Gross Margin = Total Revenue – Total Input Costs.

Where:

$$\textbf{Total Revenue} = \left[(\text{Maize\_GY} \times \text{Pmg}) + (\text{Legume\_GY} \times \text{Plg}) + (\text{N}_2 \times \text{Pn}) + (\text{Maize\_SY} \times \text{Pms}) + (\text{Legume\_SY} \times \text{Pls})\right]$$

- o **GY** is the grain yield
- o **SY** is the stover yield
- o **Pmg, Plg, Pn, Pms and Pls** are the average market prices of maize grain, legume grain, nitrogen, maize stover and legume stover, respectively.
- o $\mathbf{N_2}$ is the calculated residual nitrogen from BNF as explained in section 2.4.1

Total Input Costs = Sum of costs for fertilizers (organic and inorganic), seeds, labour (estimated at $4/labour day) and agrochemicals. Input and output costs were based on average prices during the 2020/21 agricultural season (SM Table 4). The quantity of inputs used was calculated based on the area under each crop, obtained from the survey.

Return on investment (ROI) was calculated using the formula:

$$ROI = \left(\frac{Gross\ margin}{Total\ Input\ Costs}\right) x\ 100$$

A positive ROI indicates that the investment is profitable, while a negative ROI indicates that the investment is unprofitable.

2.5. Statistical analysis

Data analysis was conducted using R-software version 4.1.3. The data were tested for normality using the Shapiro-Wilks test. Significance levels were set at $P \leq 0.05$. A Chi-square test was used to compare the differences in the proportion of PDs and LEFs that adopted PD practices within each farm type. A *t*-test was run to compare mean partial farm-level efficiency (obtained from DEA) between PDs, LEFs and middle-performing farms within each farm type. Additionally, *t*-tests were also conducted to compare the mean differences in crop yields, carbon and nitrogen added to the soil, partial nitrogen balance, farm productivity, gross margins and ROI between PDs and LEFs within each farm type. Generalized linear models (GLMs) were employed to identify positive deviant practices that were significantly associated with total farm productivity and milk production. Covariates including age, sex, educational level, and marital status were included in the GLMs. Packages used for the analysis included *vegan* and *ade4* for computing distance matrices, *stats* for the PCO, *hclust* for the HCA, and *deaR* for the DEA. A random forest classification model was run using the function *randomForest.*

3. Results

3.1. Description of farm types

In the farm typology, the proportions of better-off, average, and poorly-resourced farms were 45 %, 25 %, and 30 % in Mutoko and 28 %, 24 %, and 48 % in Buhera (Table 1). In Mutoko, the random forest classification model identified the mean organic amendments added to the soil, cereal production, cattle, and equipment ownership as the most discriminating variables distinguishing farm types (Table 1). In Buhera, the most discriminating variables were mean cereal production, cropped area, cattle, and equipment ownership (Table 1). In Mutoko, better-off, average, and poorly-resourced farms had a mean cereal production of 594 kg, 245 kg, and 158 kg, respectively, during the 2019/20 season, mean cattle herd size of 5.8, 3.4, and 1.2 animals, and mean equipment value of $441, $273 and $87. In Buhera, better-off, average, and poorly-resourced farms had a mean cereal production of 471 kg, 241 kg, and 137 kg, respectively, during the 2019/20 season, mean cattle herd size of 5.2, 5.5, and 1.0, and a mean equipment value of $519, $388 and $219 (Table 1).

In Mutoko, the proportion of poorly-resourced farms being female-headed was higher (66 %) than better-off and average farms (32 %). Poorly-resourced farms also had the lowest proportion of household heads whose education went beyond primary education (45 %) compared to better-off farms (55 %) and average farms (54 %). Also, in Buhera, better-off farms had the lowest proportion of female-headed households (12 %) compared to average farms (38 %) and poorly-resourced farms (44 %). Better-off farms also had the highest proportion of household heads with an education level higher than primary (68 %), compared to average farms (57 %) and poorly-resourced farms (58 %). In Buhera, there were no significant differences in household size between farm types. In both districts, livestock ownership, quantity of fertilizer applied, livestock sold, and organic amendments added to the soil significantly decreased from better-off farms to poorly-resourced farms (Table 1).

3.2. Characteristics of PDs and LEFs

In Mutoko, PDs, LEFs, and middle-performing farms within each farm type significantly differed from each other in farm-level efficiency (Table 2). Similar patterns were observed in Buhera, except that the efficiency of middle-performing farms was comparable to that of LEFs in the average and poorly-resourced farm type.

PDs generally had comparable cropping areas and slightly more TLUs than their LEF counterparts (Table 3). The crop yields and milk production obtained by PDs was substantially larger than those of LEFs. For example, in Buhera, PDs from better-off farms harvested 941 kg/ha of grain maize and 759 kg/ha of small grains, compared to their respective LEFs, who harvested 508 kg/ha and 384 kg/ha, respectively (Table 3). The differences in productivity between PDs and LEFs were more apparent among better-off farmers than among the poorly-resourced farms (Table 3).

Livestock sales occurred year-round in both districts, with PDs from better-off farms primarily selling cattle from January to July, and October to November. In contrast, LEFs mainly sold cattle during school holidays in April, August, and December to cover school fees. Poultry sales occurred throughout the year for all farm types in both districts. LEFs typically considered cattle fat from February to July and lean from August to December. Conversely, PDs considered their cattle fat almost year-round, with some considering their condition as medium from October to December.

3.3. Positive deviant practices

In Mutoko, PDs from better-off farms adopted more improved practices than PDs from average and poorly-resourced farms. PDs from poorly-resourced farms were more likely to produce and preserve fodder legumes and own livestock remedies compared to LEFs (Fig. 2). PDs from average farms tended to buy supplements, had improved livestock (cross) breeds, kept personal stock of livestock remedies, and practiced meat grading before selling. In addition to the practices implemented by PDs on from average and poorly-resourced farms, PDs from better-off farms tended to spray their livestock using hand-held sprayers and practiced pen fattening. Across all farm types, PDs tended to carry out farm operations more timely and to have fewer labour constraints. PDs from average and better-off farms tended to irrigate their fields and be more likely to apply recommended fertilizers compared to LEFs (Fig. 2).

In Buhera, artificial insemination services were accessed exclusively by better-off PDs (Fig. 3). Across all farm types, PDs tended to produce and preserve fodder and to keep personal stock of livestock remedies. Homemade and purchased supplements were more likely used by PDs from better-off and average farms than by LEFs. PDs from better-off farms tended to vaccinate livestock, engage in pen fattening, and

Table 3
Characteristics of positive deviants and low-efficiency farms in Mutoko and Buhera districts during the 2020/21 season.

		Mutoko						Buhera					
		Better-off Farms		Average Farms		Poorly-resourced Farms		Better-off Farms		Average Farms		Poorly-resourced Farms	
Variables	Season	PDs	LEFs	PDs	LEFs	PDs	LEFs	PDs	LEFs	PDs	LEFs	PDs	LEFs
Total cropped area (ha)		1.4	1.3	1.6	1.0	1.0	1.1	2.9	2.1	2.4	1.3	2.1	1.2
TLU		4.9	3.3*	2.3	1.5	1.2	0.9	5.1	4.3*	5.1	3.9*	1.5	1.0
Milk production (l/day/farm)	Wet	3.5	0.7*	3.9	2.4	0	0	2.6	2.2	1.3	0.4	1.3	0.7
	Dry	1.2	0.4	1.1	0.1	0	0	1.2	1	0.4	0.3	0.4	0.3
Maize yield (kg/ha)		2927	1354*	1531	1083*	1332	885*	941	508*	573	404*	384	215*
Legume yield (kg/ha)		2615	1016*	1185	958*	1393	925*	383	143*	362	246	238	136
Small grain yield (kg/ha)		925	371*	750	505*	750	413*	759	384*	665	410*	538	371

Where TLU refers to tropical livestock units, a ‘*’ indicates a significant difference ($P < 0.05$) between positive deviants (PDs) and low-efficiency farms (LEFs).

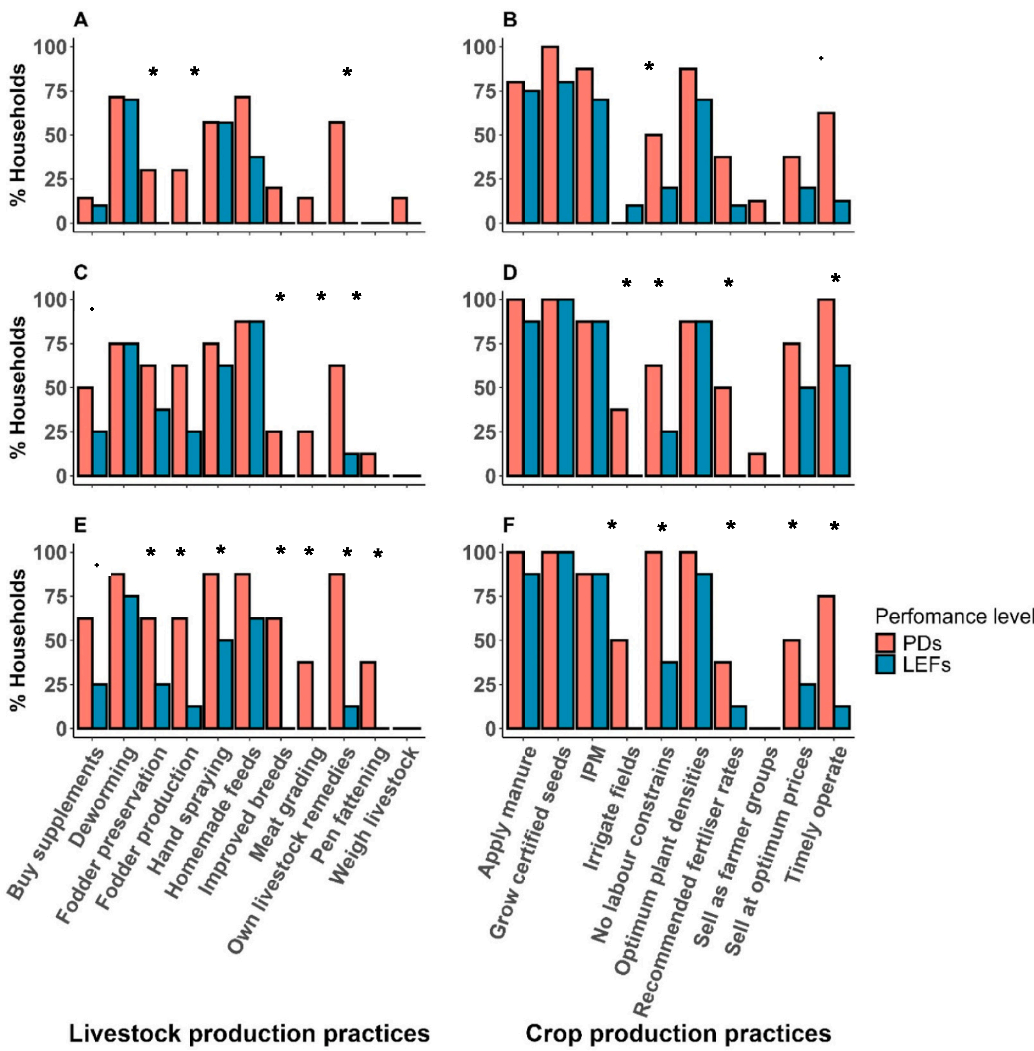

Fig. 2. Proportion of farms in Mutoko using practices identified by positive deviants for livestock (A, C, E) and for crop (B, D, F) production, within the categories of poorly-resourced farms (A, B), average farms (C, D) and better-off farms (E, F). The asterisk (*) indicates significant difference ($P < 0.05$) in the proportion of positive deviants (PDs) and low-efficiency farms (LEFs) adopting certain practices. The ability to sell at optimum prices and timely operations are examples of good management practices by PDs.

weigh livestock before selling. Similar to Mutoko, PDs in Buhera tended to carry out farm operations timely and to have fewer labour constraints across farm types. Most PDs from better-off and average farms used recommended fertilizer rates and planted crops at optimum planting densities. PDs from better-off farms tended to apply manure and sell produce at the best available market price.

The free listing provided insights into other unique practices implemented by PDs. Notably, better-off PDs in Buhera intentionally selected bulls to avoid inbreeding. Regarding crop production, some PDs in both districts, particularly from better-off and average farms, mentioned practicing winter ploughing to incorporate weeds and residues, winter weeding, and staggering planting stations and dates.

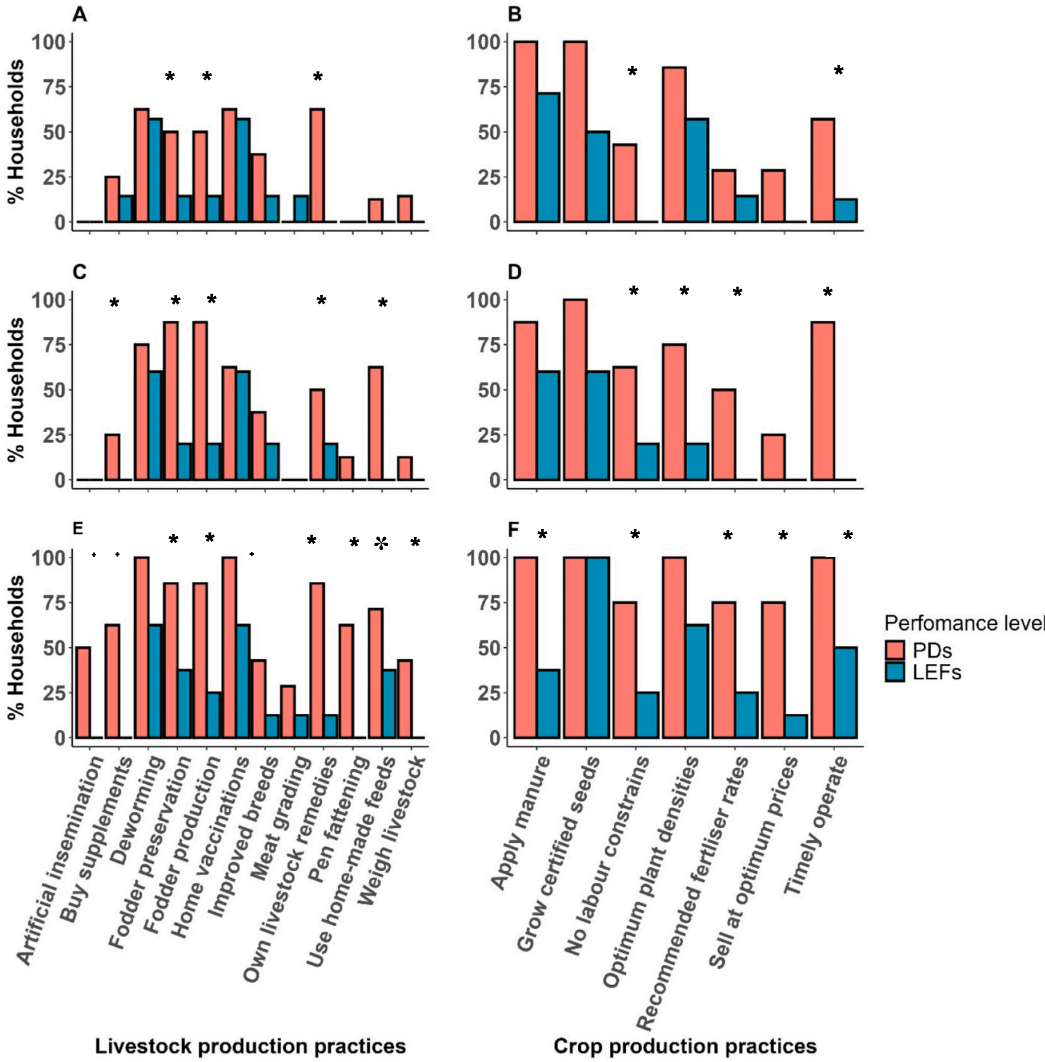

Fig. 3. Proportion of farms in Buhera using practices identified by positive deviant for livestock (A, C, E) and crop (B, D, F) production within the categories of poorly-resourced farms (A, B), average farms (C, D) and better-off farms (E, F). The asterisk (*) indicates significant difference ($P < 0.05$) in the proportion of positive deviants (PDs) and low-efficiency farms (LEFs) adopting certain practices. The ability to sell at optimum prices and timely operations are examples of good management practices by PDs.

3.4. *Key performance indicators across farm types*

3.4.1. *Carbon and nitrogen added to the soil*

Crop residues were the main source of C added to the soil in Mutoko across all farm types (Fig. 4). On better-off and average farms, manure was the second largest C source added to the soil. Overall, PDs added greater quantities of C to the soil per ha of maize field than LEFs. In Buhera, manure was the main source of C added to the soil, followed by crop residues in better-off and average farms (Fig. 4). Due to higher yields in Mutoko, the quantities of C added to the soil were almost double those in Buhera across farm types.

The main source of N applied to maize fields was ammonium nitrate (Fig. 5), used as a top dressing. In Mutoko, compound D applied as a basal fertilizer, and crop residues applied as mulch were other main N sources across farm types. Generally, PDs added greater quantities of N to the soil than LEFs. Only better-off PDs in Mutoko applied more than 200 kg/ha of N to their maize fields (Fig. 5). Compound D was commonly used across farm types. Additionally, leaf litter was a source of N used primarily by poorly-resourced PDs in Buhera and poorly-resourced LEFs in Mutoko. Across farm types, the quantities of N added to the soil in Buhera were at least 50 % lower than in Mutoko probably due lower rainfall received.

In both districts, C and N added to the soil were significantly correlated to grain yield. The correlation coefficients for C added to the soil and crop yield were 0.65 in Buhera ($P < 0.001$) and 0.40 in Mutoko ($p = 0.005$) (SM Fig. 1). Similarly, the correlation coefficients for N addition were 0.62 in Buhera ($P < 0.001$) and 0.30 in Mutoko ($P = 0.039$).

3.4.2. *Partial N balance*

The main inputs of N at farm-level were inorganic fertilizer applications and biological nitrogen fixation, while the main exports of N were crop residues grazed by other people's livestock and harvested grain. Given the greater nitrogen fixation and fertilizer use on PD farms compared to LEFs, PDs had more positive partial N balances. An exception was observed in Mutoko, where LEFs had greater partial N balances than PDs, although this difference was not statistically significant (Table 4).

3.4.3. *Systems' productivity*

Overall, crop production contributed significantly more to total farm productivity than livestock production (Fig. 6). In Mutoko, PDs had substantially greater total farm productivity (defined by livestock and

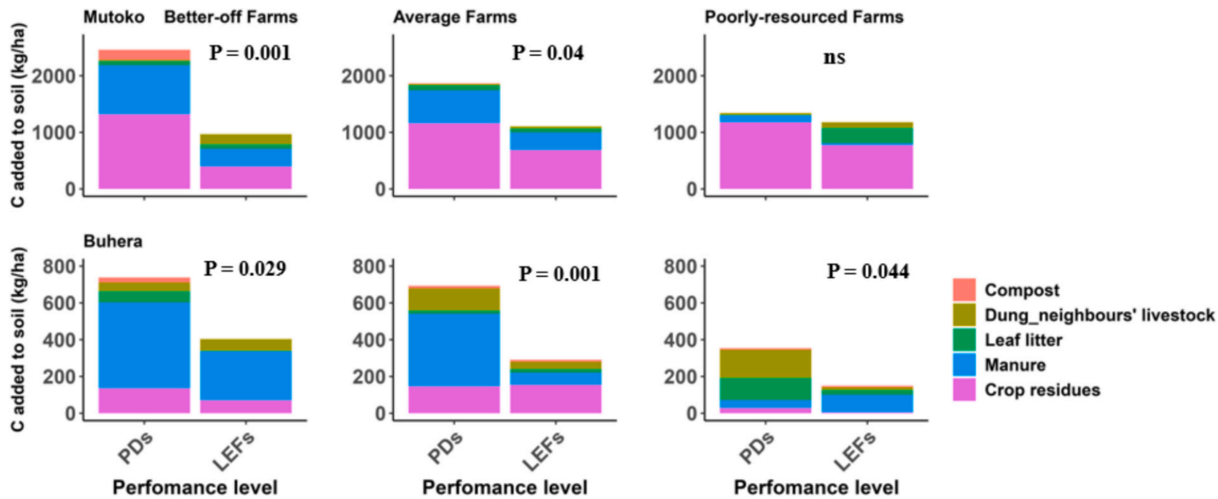

Fig. 4. Sources and quantities of carbon added to the soil of maize fields in Buhera and Mutoko districts during the 2020/21 season. The numbers displayed above each plot represent the *P*-values from the *t*-test comparing the mean carbon added to soil by positive deviants (PDs) and low-efficiency farms (LEFs). Significance was tested at $P < 0.05$.

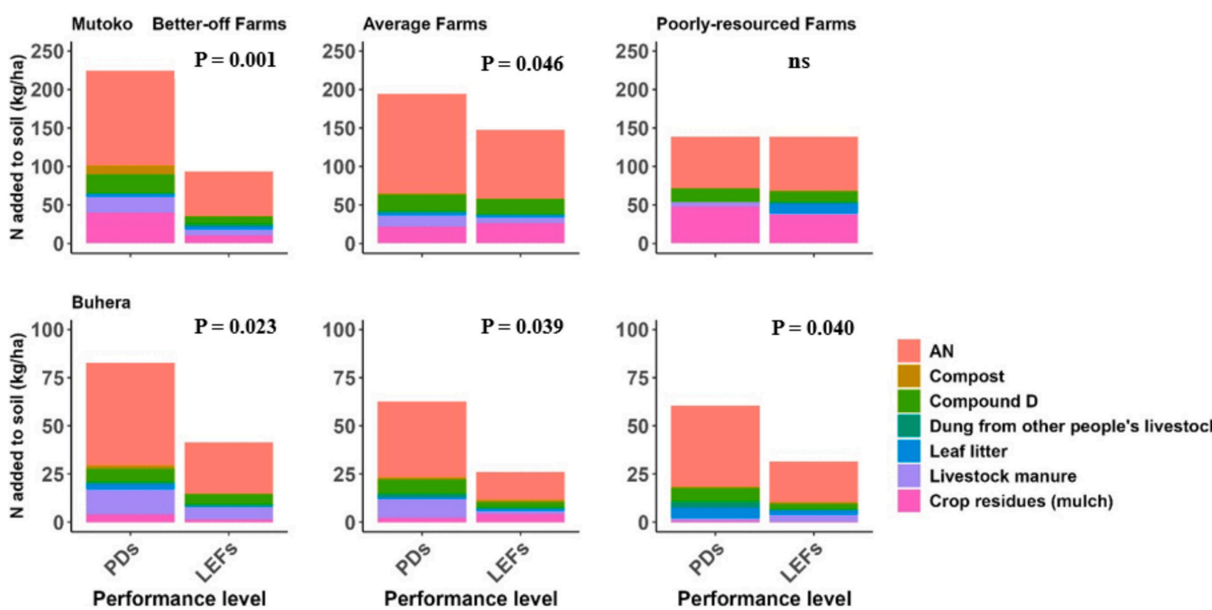

Fig. 5. Sources and quantities of nitrogen (N) added to the soil in Buhera and Mutoko districts. Where AN means ammonium nitrate. The numbers displayed above each plot represent the P-values from the t-test comparing the mean nitrogen added to soil by positive deviants (PDs) and low-efficiency farms (LEFs). Significance levels were set at $P < 0.05$.

Table 4
Partial N balance within each farm type.

District	Performance	Partial N balance (kg/farm)		
		Better-off Farms	Average Farms	Poorly-resourced Farms
Buhera	PDs	98	109	82
	LEFs	57*	75*	38*
Mutoko	PDs	115	82	59
	LEFs	57*	45*	69

The asterisk '*' after the % difference indicates a significant difference ($P < 0.05$) in mean partial nitrogen balance between PDs and LEFs.

crop energy outputs) than LEFs. In Buhera, all PDs had higher total farm productivity than their respective LEFs, except for poorly-resourced farms (Fig. 6). Overall, total farm productivity in Buhera was nearly half of that in Mutoko across farm types indicating regional differences in agricultural productivity.

Generalized linear models showed that in Buhera, total farm productivity was significantly associated with the ability to deworm livestock, application of recommended fertilizer rates, and availability of labour (SM Table 3). In both districts, the use of homemade and purchased supplement feeds was significantly associated with milk production on better-off farms. However, none of these practices were significantly associated with total farm productivity on poorly-resourced farms in either of the districts.

3.4.4. *Gross margins and return on investment of farm types*

In both districts, PDs from better-off farms generated higher revenues from crop production than LEFs (Table 5). PDs also achieved higher ROI than LEFs, suggesting better resource utilization (Table 5). On average-resourced farms, PDs outperformed LEFs on all economic indicators, although differences in gross margin were marginally significant in Buhera (*P*-value = 0.057). For poorly-resourced farms in Buhera,

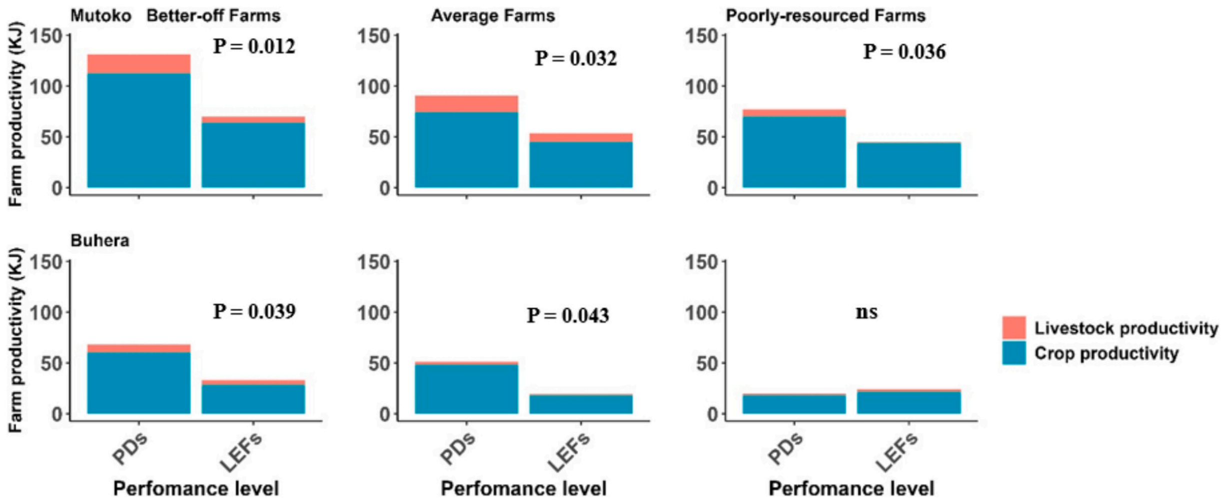

Fig. 6. Total farm productivity of three farm types in Mutoko (*N* = 8) and Buhera district (N = 8).
The numbers displayed above each plot are the P-values of the t-test comparing the positive deviants (PDs) and low-efficiency farms (LEFs). Significance levels were set at P < 0.05.

Table 5
Mean gross margins and return on investment of positive deviants (PDs) and least-efficiency farms (LEFs) in different farm types of Buhera and Mutoko Districts. The numbers in brackets represent the standard deviation of means.

		Buhera			Mutoko		
Farm Type	Variable	PDs	LEFs	P-value	PDs	LEFs	P-value
Better-off	Revenue (USD)	882 (228)	417 (76)	0.002	1201(807)	674 (110)	0.028
	Input costs (USD)	707 (206)	506 (211)	0.024	693 (359)	499 (186)	0.049
	Gross Margin (USD)	175 (88)	−90 (54)	0.008	509 (222)	176 (108)	0.044
	Return on investment (%)	35 (9)	−8 (19)	0.019	99 (49)	62 (43)	0.047
Average-resourced	Revenue (USD)	656 (223)	216 (130)	0.007	805 (291)	563 (175)	0.018
	Input costs (USD)	605 (143)	279 (83)	<0.001	489 (122)	387 (157)	0.028
	Gross Margin	52 (59)	−63 (55)	0.057	317 (170)	176 (134)	0.033
	Return on investment (%)	10 (74)	−13 (62)	0.049	81 (61)	45 (22)	0.03
Poorly resourced	Revenue (USD)	209 (205)	200 (224)	ns	370 (240)	212 (77)	0.037
	Input costs (USD)	285 (157)	331 (264)	ns	208 (11)	181 (96)	ns
	Gross Margin (USD)	−76 (201)	−131 (154)	ns	163 (235)	31 (98)	0.04
	Return on investment (%)	−27 (61)	−37 (35)	ns	77 (109)	37 (51)	ns

all gross margins and ROI were negative. In Mutoko, poorly-resourced PDs performed significantly better on all metrics except for ROI, which was comparable to that of LEFs (Table 5). While margins were low, PDs generated a small profit, and their revenues were slightly greater than those of LEFs. All in all, differences in economic performance between PDs and LEFs were more pronounced among better-off and average-resourced farmers than among poorly-resourced farmers.

4. Discussion

4.1. Description of the farming systems

The study illustrated the heterogeneity of farming systems in Mutoko and Buhera Districts of Zimbabwe (Table 1). This heterogeneity implies varying capacities among farmers to adopt innovations, effectively manage resources and improve agricultural productivity. Therefore, this approach helps to tailor recommendations to the specific needs of different farm types. Several studies (Baudron et al., 2024; Chikowo et al., 2014; Dunjana et al., 2018; Mkuhlani et al., 2020) have implemented this approach in Zimbabwe.

Better-off farms achieved higher levels of productivity due to greater resource endowment in terms of cattle, access to equipment, and quantities of organic and inorganic inputs used. As a result, they engaged in more mechanized and timely land preparation, applied greater quantities of both organic and inorganic fertilizers, and diversified their production systems to include crops and livestock. The ability to integrate livestock and crops leads to farm diversification, and may enhance nutrient cycling and farm resilience to shocks such as droughts (Kuivanen et al., 2016).

In contrast, poorly-resourced farms were highly constrained in their access to livestock, inputs, and equipment, often relying on low-cost practices such as the use of leaf litter. The application of fertilizers and organic amendments was constrained by affordability and by limited access to livestock manure due to small herd sizes and communal grazing systems. These households sold their labour, which may have led to delays in land preparation and planting. Crop and livestock production on these farms were generally less integrated, thereby missing out on potential synergies that could improve productivity. Consequently, these poorly-resource farms had the lowest resource use efficiency of the three farm types, supported by the gross margins and ROI (Table 5). Other studies also demonstrated that resource-constrained farmers tend to be characterized by low equipment value, cereal production, livestock ownership and organic amendments application rates (Dunjana et al., 2018; Zingore et al., 2007).

The average-resourced farms had moderate access to resources and production inputs. In Buhera, these average farms had cattle numbers and cropped areas comparable to those of better-off farms, implying that with good management skills such as timely planting and following extension services, these may develop into ‘better-off farmers’. This highlights that resource endowment alone does not fully explain differences in productivity and efficiency between farm types. Management capacity and decision-making also contributed to farm-level efficiency. For example, agricultural knowledge has been shown to improve agricultural productivity (Savikurki, 2013).

4.2. Comparison between PDs and LEFs

The differences between PDs and LEFs could largely be attributed to the ways resources were utilized rather than resource access. PDs achieved greater ROI by adopting practices that maximised output per unit input (Table 5). These findings align with earlier research showing that PDs are not always the most well-resourced, but those who use available resources more effectively and adaptively (Savikurki, 2013).

In livestock production, PDs achieved higher milk yields and livestock offtake rates. Vaccination and disease control routines provided by the government of Zimbabwe are often inconsistent and inadequate (Mutenje et al., 2014). Consequently, the ability to apply livestock remedies and administer home vaccinations outside free government schedules reduces cattle mortality. Additionally, artificial insemination is preferred for introducing desirable characteristics into livestock herds. For instance, local breeds typically have a smaller frame, and their meat is often graded as economy (Tawonezvi, 2022). Hence, artificial insemination enhances herd frame size and improves meat quality to meet commercial standards. Furthermore, Chakoma et al., (2016) reported that producing own livestock feed improves gross margins, making it a cost-effective option for availing feed.

Good management and practices such as planting on time, adding organic and inorganic fertilizers, and use of hybrid seeds were associated with higher PDs' crop productivity (SM Table 3). Although hybrid seeds offer less autonomy due to their reduced ability to be retained for future planting, they may be drought-tolerant and possess other beneficial traits that result in higher grain yields and gross margins compared to open-pollinated varieties (Hamadziripi et al., 2024). While input costs in crop production were greater for PDs than for LEFs, gross margins justified the investments, indicating the financial sustainability of PD practices (Migose et al., 2019). The greater input costs incurred by PDs, resulting in substantially higher returns, characterize the PD approach as smart farming, rather than low-cost farming.

The poorly-resourced farms and LEFs in Buhera are on the edge of viability, as evidenced by negative gross margins. A study in Murehwa also showed higher gross margins on better-off farms than poorly-resourced farms (Manyanga et al., 2025). The poorly-resourced PDs in Mutoko achieved small profits, demonstrating that even poorly-resourced farms can succeed with efficient practices. However, these farms remain vulnerable to rising input prices or unfavourable seasons, which could threaten their sustainability. Contrary, PDs in better-off farms find it easier to comply with PD practices compared to those in average and poorly-resourced farms, due to their greater resource endowment and access to extension services.

LEFs, even within better-off farm types, applied less improved practices or responded less proactively to production constraints. Many LEFs delayed planting due to poor planning or labour shortages, left crop residues unutilized and exposed to communal grazing, or failed to adopt improved breeds or feeding strategies. Furthermore, some LEFs kept cattle for social status and only sold livestock when they were injured, sick, or when a genuine need arose (Makiwa et al., 2023; Mutenje et al., 2014), leading to low livestock offtake rates. Although LEFs with few or no livestock could ideally retain their crop residues as mulch, compost, or incorporate them into the soil, they generally left them in the field, susceptible to communal grazing and burning. Yet, the addition of soil carbon and nitrogen to degraded croplands was associated with greater maize grain yield (SM Fig. 2), as also noted by Mujuru et al. (2016) and Sileshi et al. (2025). The low cereal production by LEFs also resulted in low crop residue production, yet crop residues are in demand as livestock feed and/or soil amendment.

4.3. Methodological considerations

Although DEA proved a useful tool in selecting PDs and LEFs based on efficiency, there are some limitations to this methodology. Firstly, agricultural efficiency can be influenced by external factors such as weather conditions and market prices (Haile et al., 2017). However, the second round of collecting data on farm productivity in the 2020/21 season confirmed that the methodology indeed identified PDs that were more productive than LEFs. The validation of the generated list of PDs and LEFs by agricultural extension workers also confirmed the methodology used.

The focus on efficiency in this study may introduce a bias towards practices that yield short-term gains, such as the use of inorganic fertilizers, at the expense of long-term sustainability. Nevertheless, in the current context, farms utilising more inputs, including fertilizers (PDs), are also likely the more sustainable farms from an economic and environmental perspective. Figs. 4 and 5 illustrate that these farms contribute more nutrients (carbon and nitrogen) to the soil, while Table 3 shows increased legume yields, indicating high residue outputs and nitrogen inputs from biological nitrogen fixation. Importantly, most PDs returned harvested crop residues to their fields, thereby minimizing nutrient exports. Additionally, PDs consistently outperformed LEFs in gross margins and ROI (Table 5), indicating a greater return on input investments. To provide a more holistic understanding of farm performance, other metrics such as farm diversification, profitability and environmental sustainability could also be used alongside efficiency. There may be trade-offs between efficiency and some of these other metrics. For example, while efficiency may streamline operations to maximize output with minimal input, it may lead to specialization and monoculture practices (Tacconi et al., 2022). In contrast, diversity in crops and livestock enhances resilience against pests, diseases and market fluctuations (Tacconi et al., 2022). However, diversity may reduce efficiency due to the complexity of managing such systems.

The dominance of crop production in total farm productivity (kJ) was due to the low livestock off-takes relative to crop production. It is important to note that while crops contribute substantially to the overall energy output, livestock products tend to fetch greater market price per kilogram (Ngoma et al., 2023), which in turn affects the economic valuation of farm productivity differently.

4.4. Constraints of LEFs to adopt PD practices

Although some PD practices may be accessible to most farmers, several factors constrain their adoption by LEFs. These include i) lack of financial capital to purchase key inputs such as improved seeds, fertilizers, and veterinary products (Bonilla-Cedrez et al., 2021; Masere and Worth, 2021), ii) poor access to knowledge and extension services, iii) labour constraints as LEFs tend to sell out labour leading to delayed planting, etc. iv) prioritizing keeping livestock for prestige over productivity and v) being risk averse, especially in marginal environments where farmers fear crop failure or livestock losses.

To support the transition of LEFs to PDs, targeted interventions are needed to address resource and capacity gaps. To facilitate the adoption of PD practices, farmers may need to access credit facilities, subsidized fertilizers and farm machinery, and an adequate extension officer-to-farmer ratio (Bonilla-Cedrez et al., 2021; Masere and Worth, 2021). Field tours and farmer field days could be used to strengthen extension services and foster peer learning. It is possible to unlock the potential of LEFs to become PDs by creating an enabling environment where good practices are viable and valued.

5. Conclusions and recommendations

The study identified three farm types based on resource endowment: better-off, average, and poorly-resourced farms. The study demonstrated the improved agricultural productivity and efficiency of PDs, supported by key performance metrics such as gross margins, ROI, farm productivity (kJ), as well as C and N additions to the soil. The differences between PDs and LEFs were largely attributed to the way resources were utilized, rather than resource access. Good management and PD practices such as carrying out operations on time, use of hybrid seeds and application of recommended fertilizer rates were associated with greater crop productivity and ROI among PDs. The better performance of PDs with respect to livestock offtake rates was made possible by selling livestock with good meat quality and a better frame, thanks to cross-breeding, supplementary feeding and the ability to control diseases and access veterinary services outside free government schedules.

The lower adoption rates of these productivity-enhancing practices on poorly-resourced farms highlight the barriers faced by these farmers, such as lack of financial resources. To bridge the gap between PDs and LEFs, targeted interventions are needed. These could include providing starter packs for fertilizers and livestock drugs, improving access to credit, subsidizing fertilizers, ensuring access to farm machinery, and reducing the extension officer-to-farmer ratio for better support. It is recommended that agricultural practitioners tailor recommendations to the specific needs of different farm types and actively promote PD practices at local level to enhance agricultural productivity.

CRediT authorship contribution statement

Eleanor Florence Mutsamba-Magwaza: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Frédéric Baudron:** Writing – review & editing, Supervision, Software, Methodology, Conceptualization. **Angelinus C. Franke:** Writing – review & editing, Supervision, Methodology, Investigation. **Elmarie Van Der Watt:** Writing – review & editing, Supervision. **Isaiah Nyagumbo:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare none.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2025.104397.

Data availability

Data will be made available on request.

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