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Efficacy of Risk Reducing Diversification Portfolio Strategies among Agro-Pastoralists in Semi-Arid Area: A Modern Portfolio Theory Approach

Ponsian T. Sewando

Abstract

Agro-pastoralists in the tropical semi-arid dryland areas of sub-Saharan Africa are significantly affected by climate change and variability. The agro-pastoral families are coping with production-related climatic risks through livelihood diversification to ensure food security. Data were collected from a sample of 411 agro-pastoralists across five districts in the semi-arid northern and central regions of Tanzania through survey conducted between November 2017 and July 2018. Secondary data regarding crop yields and livestock populations for eight years from 2009 to 2017 were collected from the National Bureau of Statistics and the respective District offices. Results show that about three-quarters of the agro-pastoralists managed diversified crop and livestock portfolios with two or more crops and animal species. However, simulated crop yields reveal positive correlations. Construction of integrated portfolios that generate good returns at a modest risk can be achieved through strategic choices between high-return high-risk and low-return low-risk crop and livestock activities. Thus, the paper recommends for costly long-term breeding and genotype improvement programs, strategically changing the make-up of the current crop and livestock portfolios which appear to be an affordable and tailored solution for building risk resilience among agro-pastoral communities in the drylands.

Keywords: modern portfolio theory, climate change and variability, farm returns, risks, variability

1. Introduction

Farming systems in sub-Saharan Africa (SSA) are especially vulnerable to natural hazards, as they are typically dependent on natural resources, such as limited and erratic rainfall with high inter- and intra-annual variability, pests and diseases, nutrient-poor soils and other natural calamities [1]. Weather and climate, with its inherent variability, means that farmers are facing risk, entailing either reduced or total production failure [2].

Effects of climate change on agriculture will be most adverse in regions that already suffer from high temperatures and low precipitation [3]. Such regions include the semi-arid drylands of SSA, where over three-quarters of the cropland is depends on the weather as it is rain-fed, hence further amplifying the sensitivity of agriculture to precipitation [3]. The expected increases in temperature for SSA is estimated to range from 2.0 to 4.5°C by 2100, while the annual rainfall for individual countries is expected to change by −39 to +64 mm by 2030 [4].

In order to cope with, and adapt to, climate change and variability, agro-pastoralists in the tropical areas of SSA are pursuing diversified livelihood strategies in crop and animal agriculture for enhancing food security. Crops are grown and livestock kept in diverse mixtures of varying sensitivity to production risks in order to ensure farm income and reduce the risk of failure [5]. Ref. [6] shows clearly that in semi-arid environments, combining crop production and livestock diversifies livelihoods. With limited public investments in planned adaptations, agro-pastoralists remain vulnerable to climatic risks while relying mostly on their autonomous coping strategies and adaptations.

The strategic diversification choices not only spreading risk [7], but also provide an important hedge against risk [8]. It is not prudent to invest all resources in highly correlated activities that may all perform poorly at the same time. Therefore, investing in two or more activities, whose returns are not full correlated, reduces the overall volatility below that of each one being taken separately [9]. As managers, agro-pastoralists guarantee food security by reducing the volatility of their farming by seeking a mix of farming activities that have either a small or negative correlation of related returns. This is critical for agro-pastoralists pursuing their livelihoods amid climatic risks are being further aggravated due to climate change.

Moreover, agricultural diversification enhances food security and farm income thus mitigating climate-related production risks [10]. Each crop-livestock combination has specific returns and risks. However, few studies evaluate the returns and risks associated with various crops and livestock portfolios among agro-pastoral farmers in the dryland areas of SSA.

This paper contributes to bridging this research gap by evaluating the levels of returns and risks associated with crop-livestock portfolios among agro-pastoralists in the semi-arid areas of Northern and Central Tanzania. The Modern Portfolio Theory (MPT) was used to evaluate risk in corporate and financial portfolio management, to evaluate the returns and risk of different crop-livestock portfolios which enhance food security. The results of this study inform the strategic diversification choices for enhanced resilience of agro-pastoralists in the face a changing climate.

2. Methodology

2.1 Theoretical framework

Smallholder agro-pastoral farmers are struggling to adapt to climate change and variability in order to maximize their utility (welfare) by safeguarding their livelihoods. The classical economic analysis of decision-making in the presence of risky and uncertain outcomes is based on Expected Utility (EU). EU theory underlies choices under risk [11]. EU theory provides a framework for modeling the choices of a rational individual whose goal is to maximize expected utility [12]. The underlying assumption of EU theory is that individuals have stable and coherent preferences; they know what they want and they examine the available alternatives before selecting the one that they judge to be best [13].

According to [12], rational choice theory is based on a model comprising two components: 1) a group of alternatives that are possible to realize, under different conditions; and 2) an individual's preferences that reflect their goals. However, the EU theory framework is criticized because it assumes that decision-makers are familiar with the probability distributions of each alternative outcome [12]. This is a serious theoretical flaw underlying EU in the face of climate change, which is inherently endowed with uncertainty [14, 15], not risk. Other complex alternative frameworks are suggested in the literature, including Subjective Utility Theory, Maxmin, α-maxmin, Minmax Regret, Maxmin EU, Smooth Ambiguity and Variational Preferences (Heal and Millner 2013). Kahneman and Tversky (1979) present a critique of expected utility theory as a descriptive model of decision making under risk and develop an alternative model, which they call *prospect theory*.

Despite its shortcomings, EU is still a useful theoretical framework for understanding the choices of agro-pastoral household livelihood activities. This is because agro-pastoralists in the semi-arid tropical drylands have lived with the vagaries of weather extremes for generations. In this regard, they have learned the patterns of climatic risks that impact their livelihood activities, meaning that risks due to climate change will not be a completely new experience.

Extremely risky situations, such as natural disasters, like climate extremes, have a significant effect on the probability distributions, resulting in the tails of the distribution being emphasized. On the other hand, investment alternatives, such as adaptations, are determined by the shape and symmetry of the expected outcome distributions [12]. Markowitz's method of optimization [16] in the context of Modern Portfolio Theory (MPT), can be adapted to include anomalies, heavy-tailed and asymmetric distributions, as well as more sophisticated measures of extreme risks. These technical attributes support its use in risk analysis in riskier undertaking such as crop and animal agriculture in the dryland farming systems.

In this paper, we extend EU theory into the MPT framework in order to analyze alternative portfolios of crop and livestock types by agro-pastoralists in terms of their returns and associated risks. MPT uses information about the joint probability distribution of outcomes of all possible assets in a portfolio (including means, variances, and covariances) in order to select a portfolio that efficiently manages risk [17]. Although MPT has been applied to financial and corporate portfolio management since the 1950s, its potential for analyzing climate change adaptation and resilience by evaluating returns of livelihood activities and associated risk remains unfulfilled.

The MPT framework is increasingly adapted for risk management in agriculture, in particular focusing on diversification in agriculture and forestry for reasonably higher and stable output in the face of uncertain climate [1, 3, 18]. There are three assumptions of MPT for diversification: (i) there is more than one possible investment at any given time; (ii) these investments are subject to risk; and (iii) that the same economic and environmental conditions do not affect all investments equally [19].

The livelihood resilience of agro-pastoralists in the face of climate change and variability would be enhanced if crop-livestock portfolios generate upgraded returns with minimal variances. Optimal diversification by combining activities with low positive covariance and income-skewing is a primary risk reducing strategy. This is achieved by reducing the risk of the overall return by selecting a mixture of activities whose net returns have a low or negative correlation [20]. This means that farmers spread risk by diversifying the allocation of productive assets across various income-generating activities, often preferring farm plans that provide a satisfactory level of security even if this means sacrificing income on average [21].

Agro-pastoralists might wish to avoid income fluctuation and to maximize income at the same time. Since farms can be thought of as assets within an overall portfolio, agricultural producers might behave in a manner like investors who pay attention to the concept of diversification. However, agro-pastoralists might not have considered diversification in the same way that the typical financial investor might: they often look at diversification as changing their crop mix, rotational system, and livestock breeds, or even as cultivating spatially separated farms [22] and splitting livestock across distant grazing locations [23]. Despite the relevance of considering these forms of diversification, our analytical scope is limited to diversification of alternative combinations of crop and livestock enterprises. However, it highlights possible future research for increasing the scope of portfolio diversification in SSA.

2.2 The study area

The study was conducted in the semi-arid drylands of northern and central Tanzania, covering five districts namely Mwanga, Arusha, Babati, Kongwa and Ikungi from Kilimanjaro, Arusha, Manyara, Dodoma and Singida regions, respectively. The long-term temperatures and rainfall (1990–2016) were analyzed by considering averages of five base years from 1990 to 1995 and the five years of 2009–2016. The aim was to investigate if there was a notable shift in temperatures and rainfall in over the long-term. Unlike comparing a single base (1990) and terminal year (2016), the clusters of five years in the base and terminal periods facilitate capturing intermittent annual volatility.

The average annual monthly minimum temperature has increased by around 1°C in northern Tanzania (**Table 1**). This means that over time, months that used to be cooler are getting warmer. The maximum temperature has risen by 0.3°C in Arusha and 0.9°C in Mwanga. The standard deviations are larger, thus indicating increased volatility of temperatures. Rainfall has only increased marginally in Mwanga and Babati (+16.3 and + 1.3 mm, respectively) and decreased by 72.2 mm in Arusha. The magnitudes of standard deviations indicate higher inter-rainfall annual variability.

In the central semi-arid areas, in the cooler months, Kongwa has become warmer by about 1°C, while warmer months have registered an average increase of about 0.4°C over time (**Table 1**). Ikungi has registered marginally decreasing (−0.3°C) minimum and increasing (+0.1°C) maximum temperatures. In terms of

Study locations	Temperature (°C)				Rainfall (mm)	
District	Base years [earliest 5 years[ψ]]		Now [recent 5 years[†]]		Base years [earliest 5 years[ψ]]	Now [recent 5 years[†]]
	Min	**Max**	**Min**	**Max**		
Mwanga	17.0 (0.32)	29.9 (0.82)	18.1 (0.36)	30.7 (0.34)	431.9 (146.7)	448.2 (80.9)
Arusha	14.4 (0.26)	26.0 (0.61)	14.9 (0.29)	26.3 (0.47)	775.1 (195.9)	702.8 (132.7)
Babati	na	na	na	Na	584.4 (183.3)	585.7 (227.9)
Kongwa	16.8 (0.40)	29.0 (1.28)	17.6 (0.14)	29.4 (0.19)	517.2 (30.0)	566.6 (168.5)
Ikungi	16.5 (0.58)	27.5 (0.38)	16.2 (0.17)	27.6 (0.34)	608.5 (188.8)	668.8 (193.9)

Numbers in open and closed brackets are averages and standard deviations, respectively; na = data not available.
[ψ]*Base earliest 5 years between 1990 and 1995.*
[†]*The 5 years between 2009 and 2016.*

Table 1.
Average monthly annual temperature and rainfall trend in the study areas.

rainfall, locations in central Tanzania have experienced an increase of monthly annual average rainfall between 50 and 60 mm.

Generally, over time, the study locations are getting warmer and experiencing an increase in rainfall. However, larger standard deviations, particularly with rainfall, indicate higher variability. Increasing temperatures will counteract marginal increases in rainfall through increased evapo-transpiration, thus inducing stress on plant and animal production. While our results highlight the general trend in temperature and rainfall, a more rigorous analysis of rainfall distribution in terms of the number of rainy days would provide more information on the rainfall distribution, which is what matters most for agricultural production.

2.3 Research design and sampling

This study used a cross-sectional survey design that allowed data to be collected at a single point in time, while still having a broad scope. The study used crop livestock panel data over the period of 8 years (2009–2017), available at the district level, are also used in the analysis. A simplified formula for proportions by [8] is adopted in order to obtain the desired sample size of agro-pastoralists in semi-arid northern and central Tanzania, assuming 95% confidence level and 0.05 as sampling error; the formula is as follows in Eq. 1:

$$n = \frac{N}{1 + N\left(e^2\right)} \tag{1}$$

where n is the sample size; N is the population size; and e is the level of precision i.e. sampling error.

Using the above formula, a total of 411 agro-pastoral households were sampled.

A multi-stage sampling approach was employed in order to select the study locations and, ultimately, the individual agro-pastoral households. The study locations from region, district, ward, and down to the village were selected based on the criteria of having the largest number of agro-pastoralists. The study covered 5 regions, each represented by one district, as well as an overall total of 12 wards and 23 villages. The last stage was random selection of agro-pastoral farmers from lists of heads of agro-pastoral households as provided by agricultural field officers in the selected sample villages.

2.4 Data types and data collection

Both primary and secondary data are used in this study. Primary data were collected through structured household questionnaire interviews. The questionnaire covered among other information, the production costs, yields and sales. Secondary data were collected from respective offices at the meteorological weather stations, the National Bureau of Statistics (NBS) online database, and district offices. The secondary data included historical crop yields and livestock numbers, with the latter expressed in livestock units (LU). The conversion of different livestock species into a standard LU was based on the coefficients suggested by [24]: one animal representing 0.7, 0.1, 0.1 and 0.01 LU for cattle, goat, sheep, and chickens, respectively.

2.5 Data analysis

2.5.1 Adapted definitions of MPT terminologies

Beforehand, it was important to present the conventional MPT terminologies and how they were applied in this paper (**Table 2**).

Terminology	Usage in financial investments and in this paper
Asset/securities	Items within a portfolio which refers to crops and livestock species kept by the agro-pastoralist.
Correlation	A measure of the degree to which the change in the return of two assets is similar. It represents correlations of crop and livestock activities.
Diversification	Investing in different assets that together make up a portfolio. It refers to crop and livestock activities.
Efficient portfolio	A portfolio offering maximal expected return at a chosen level of risk or minimal risk at a given return. In this study, it is the crop and livestock portfolio giving relatively higher returns at given levels of risk.
Portfolio	Set of financial assets held by an investor. It refers to the crop and livestock combinations pursued by the agro-pastoralist.
Return	Financial returns from a financial investment asset. The concept refers to the value of crop outputs and livestock units managed by the agro-pastoralist.
Risk	The uncertain outcome of a financial investment expressed as standard deviations or variance. It refers to the standard deviations associated with returns from crop and livestock portfolios.

Table 2.
Terminologies of the MPT as applied in this paper.

2.5.2 Incorporating local management into district crop yields and livestock units

The cross-sectional survey used in our study cannot generate longer time series data because even recalling data from five-years before is problematic as smallholder farmers do not keep records. In order to predict future (expected) returns for crop and livestock portfolios, frequently the historical performance of respective returns are examined [25, 26]. The secondary data for eight years (2009–2017) are the longest time series of crop yields and livestock numbers available from the study districts. These secondary data were the basis for simulating the distributions of future expected yields and livestock units.

Given the nature of data collection and management systems of family farms, the aggregated district-level data can have biases and errors resulting from the aggregation process. Common crop yield estimates are often based on rough estimates of aggregate production and area harvested. Owing to significant variation in farming practices and growing conditions across farming systems and agro-ecological zones, higher-level yield estimates may differ starkly from local yields realized by any given smallholder farmer [27]. According to [28], yields and related economic returns vary overtime and space, with this variation important for understanding the vulnerability of farms to climatic risks. Therefore, we used the cross-sectional household survey crop yields and livestock units to normalize respective district-level data. The normalization tends to localize aggregated data thus improving the reliability and validity of yields and livestock units at the local scale. The normalization approach is adapted from the work of [28] as follows in Eq. 2.

$$\beta_{aij} = y_{aijk} / y_{hik} \qquad (2)$$

where y_{aijk} = aggregate district-level yield/livestock specie unit of ith crop/livestock type in j^{th} year of the reference production period (2009–2017), in k^{th} district; y_{hik} = average observed household yield/livestock type unit of ith crop/livestock type in k^{th} district; β_{aij} = normalization factor of aggregate district level crop yield/livestock type unit of ith crop/livestock type in j^{th} district.

The factor is used to downscale secondary aggregated crop yields and livestock units to the local context. Thus, the normalized crop yields and livestock units were used to derive returns and associated risks as shown in Eq. 3.

$$y_{nij} = \beta_{aij} \times y_{aijk} \tag{3}$$

where y_{nij} = normalized aggregate district-level yield/livestock type unit of ith crop/livestock type in j^{th} year of reference production period.

2.5.3 Expected returns of crop or livestock

The size of the returns was measured by the expected mean value of the distribution. The expected mean return $E(R)$ is given by the weighted average of all possible returns, using the probability of achieving the actual return (R_i). However, this study employs historical data, meaning that the expected or mean return R_i of an individual agro-pastoral return is derived from normalized crop yields and livestock units during the 2009–2017 period. The expected returns of crops and livestock are estimated as shown in Eq. 4:

$$\overline{R_i} = \sum_{s=1}^{n} p_s R_s \tag{4}$$

where $\overline{R_i}$ = expected return of crop enterprise per hectare over the 2009 to 2017 period of a particular crop and livestock units per household over the 2009 to 2017 period; R_s = historical actual returns, and n = number of years.

2.5.4 Risk of individual agro-pastoralist activities

The risk of an individual agro-pastoral's crop and livestock portfolios was measured using respective standard deviations. For most agro-pastoralists as "investors," risk is experienced when they engage in crop and livestock production activities that generate returns that are lower than what was expected. As a result, it is a negative deviation from the expected (average) return. In other words, each crop and livestock activity presents its own standard deviation [26]. A higher standard deviation translates into greater risk. The standard deviation of a return is the square root of the variance. In general, the variance can be calculated as shown in Eq. 5:

$$\sigma^2 = \left[\sum_{i=1}^{n} \left(R_i - \overline{R} \right)^2 \right] \div (n) \tag{5}$$

where σ^2 = variance, n = number of year, R_i = historical actual return, and $\overline{R}$ = expected returns.

2.5.5 Expected returns of a portfolio

Regardless of how the individual return was calculated, the expected return of a portfolio is the weighted sum of the individual returns from the crops and livestock that form portfolio, as presented in Eq. 6:

$$\overline{R_p} = \sum_{s=1}^{n} w_s \overline{R_s} \tag{6}$$

Where: w_s = the proportion of the value of the portfolio constituted by the current market value of the ith crops or livestock entities, that is, it is the 'weight'

attached to the crop or livestock, n = the number of crops or livestock in the portfolio, $\overline{R}_s$ = historical actual return, $\overline{R}_p$ = expected return of the portfolio.

2.5.6 Risk associated with portfolio diversification strategy

Risk is the chance that an investment's return will be different from what is expected. This includes the possibility of losing some or all of the original investment. Modern Portfolio Theory [16] offers a solution to the problem of portfolio choice for a risk-averse investor like an agro-pastoralist. The optimal portfolios, from the rational investor's point of view, are defined as those having the lowest risk for a given return. These portfolios are said to be mean–variance efficient [29]. Portfolio risk is measured by calculating the standard deviation of the historical returns or average returns of a specific investment. The standard deviation of the portfolio's rate of return depends on the standard deviations of return for its entities, their correlation coefficients, and the proportions invested. It is calculated as shown in Eq. 7:

$$\sigma_p = \sqrt{\sum_{i=1}^{n}\sum_{i=1}^{n}X_iX_j\rho_{ij}\sigma_i\sigma_j} \qquad (7)$$

where σ_p = standard deviation of the portfolio,

X_iX_j = proportion invested in each asset,

ρ_{ij} = correlation coefficients between i and j,

$\sigma_i\sigma_j$ = standard deviation of each asset, and n = number of years.

2.6 Results and discussion

2.6.1 Crops and livestock diversification in Tanzania

Diversification is widely used strategy to spread risk as crops differ in their sensitivity to climate and weather extremes. About three-quarters (77%) of the responding agro-pastoral households diversified with two or more crops. A substantial number of agro-pastoral households only grow maize (**Figure 1(a)**). The eight widely diversified crop portfolios, with at least ten counts of involved agro-pastoral households, included maize-sunflower, maize-cowpea, maize-groundnut, maize-millet-sunflower, maize-pigeon pea, maize-millet, maize-sorghum, and maize-green gram. Maize as the main preferred staple features in all major crop portfolios. With exception of maize, which is relatively sensitive to seasonal droughts and intermittent dry spells, the other crops tolerate drought, a characteristic of the semi-arid farming environment. This means that agro-pastoralists in these dryland areas tend to make a strategic choice of crop mixes in order to minimize production risks. The high preference of maize as a food staple suggests that there must be efforts in crop breeding and improvement programs in order to develop drought efficient maize varieties.

Diversification involving two or more livestock types involved around 70% of the sampled agro-pastoralists. Chickens were kept by the majority of the agro-pastoralists (**Figure 1(b)**). The prominent livestock diversification portfolios included cattle-goat-chicken, cattle-goat, cattle-chicken, and goat-chicken. Despite the fact that cattle production is highly vulnerable to seasonal droughts drying up pasture and water sources, it remains a part of the livelihood activities of agro-pastoral communities. Cattle are part of the social identity of
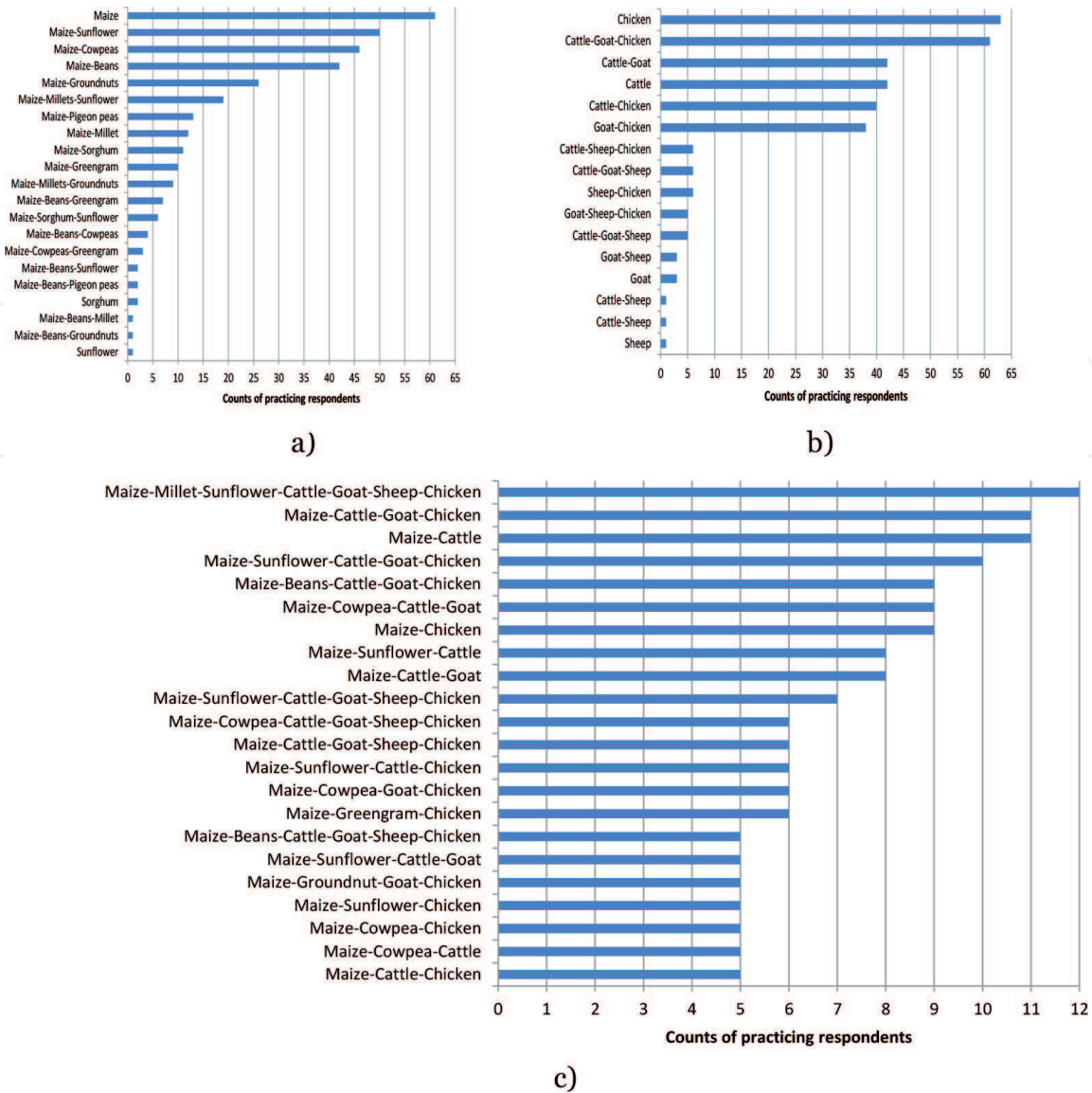
Figure 1.
Current diversification of crop and livestock portfolios. (a) Crop portfolio diversification. (b) Livestock portfolio diversification. (c) Crop-livestock portfolios diversification.

agro-pastoral societies in Tanzania. Goats, appearing in every major diversified livestock portfolio, are well adapted to the drier environment due to its ability to browse on trees and shrubs. Scavenging rural chickens can also thrive through critical drought periods.

Furthermore, diversification strategies integrating crops and livestock stand a better chance of effectively spreading production risk. Four major used diversified crop-livestock portfolios with at least ten counts of respondent agro-pastoralists include maize-millet-sunflower-cattle-goat-sheep-chicken, maize-cattle-goat-chicken, maize-cattle, and maize-sunflower-cattle-goat-chicken. Maize also features in the integrated crop-livestock portfolios. Goat and chickens, which are relatively less affected by droughts, were part of the integrated portfolios. Goats can browse on shrubs when the land lacks grazing grasses due to seasonal droughts. Cattle and sheep, which are reliant upon grasses, are highly vulnerable when grazing grounds dry up due to prolonged seasonal droughts. The prominence of cattle that are less-resilient to critical droughts and stressful heat urges for interventions to reduce risk in cattle production. Such interventions include water harvesting and storage, as well as climate-smart breeding and genotype improvement for adaptability to the drier environment.

2.6.2 Crop and livestock production with associated risks

2.6.2.1 Localized crop yields with associated risks

The district-level secondary data for seven growing seasons were localized through normalization with observed crop yields and livestock units in the survey localities. **Table 3** shows that, exception for millet, localized yields were higher than unadjusted aggregate district-level crop yields. For most crops, including sorghum, green gram, maize, groundnuts and beans, the localized yields ranged between a quarter and a half percent over the aggregate district-level yields.

The temporal volatility of locally adjusted crop yields, as reflected by the coefficients variation, was apparently higher than unadjusted district-level yields. Implicitly, local yields were highly variable with higher variances that were extended into adjusted aggregate yields through the normalization process. Although the aggregate data includes data collected outside the survey localities, it is still plausible to argue that the study locales represent the areas of respective districts. Therefore, in order to realistically reflect the local production risks faced by agro-pastoralists, downscaling higher level information is important. Furthermore, crop yields for most crops were below the national average of 1–2 tons for most for cereals and grain legumes. This reflects the higher production risks associated with crop production in semi-arid dryland areas.

2.6.2.2 Localized livestock units with associated risk

Results in **Table 4** indicate that cattle are the most significant livestock asset. Locally adjusted livestock units tended to be relatively smaller for cattle and sheep. There was some increase in the locally adjusted livestock units for goats and chickens. Given that the local livestock units were the denominator of the normalization factor, it means there were fewer goats and chicken but more cattle and sheep in the locales on average than in the rest of the respective districts. At the district scale, the numbers of goats and chickens were much variable over the period of 8 years. Locally adjusted livestock units tended to vary widely over the years, but with only limited differences across animal types. Goats and chickens are normally sold by agro-pastoralists for immediate cash needs, while decisions to sell cattle

Crops	Unadjusted district-level revenue (ton/ha)			Locally adjusted revenue (ton/ha)		
	Mean	Std. Dev.	CV	Mean	Std. Dev.	CV
Maize	265155.20	63638.00	0.24	375812.00	245828.80	0.65
Cowpeas	482332.80	352575.20	0.73	511172.00	507919.60	0.99
Beans	283974.00	89206.00	0.31	578570.00	466446.80	0.81
Sorghum	180968.80	36960.80	0.2	245302.40	136375.20	0.56
Green gram	201761.60	140492.40	0.7	335786.80	386753.60	1.15
Millets	245716.00	78527.60	0.32	235958.80	113006.80	0.48
Sunflower	179408.40	74166.00	0.41	229247.20	166135.60	0.72
Pigeon peas	70556.40	70255.60	1	125584.00	194655.20	1.55
Groundnuts	834024.40	564639.20	0.68	1395787.20	1583467.60	1.13

Table 3.
Unadjusted and locally adjusted revenue (Tshs).

Types	Unadjusted livestock			Locally adjusted livestock		
	Mean	Std. Dev.	CV	Mean	Std. Dev.	CV
Cattle	2449339.20	852204.00	0.35	750101.20	1108561.00	1.48
Goats	200464.40	141244.40	0.7	258387.20	383990.00	1.49
Sheep	103268.40	43691.20	0.41	18273.60	22033.60	1.21
Chicken	71740.80	56381.20	0.76	127069.20	150926.40	1.19

Table 4.
Unadjusted and locally adjusted livestock revenue (Tshs).

are carefully considered. Therefore, due to the volatility in the local production conditions and outputs, the aggregated information cannot be generalized for local realities.

2.6.2.3 Potential diversification of crop and livestock portfolios

An efficient portfolio is either a portfolio that offers the highest expected return at a given level of risk, or one with the lowest level of risk for a given expected return. The majority of agro-pastoralists manage combinations of two crops and two livestock species. The paired combinations of crops and livestock were the basis for developing integrated portfolios through a permutation process. **Table 5** shows one crop-livestock portfolio (Sorghum, sunflower, cattle and goat) with highest returns at a less level of risk. As presented earlier, maize is the predominant enterprise. Maize-beans-cattle-sheep had the highest returns followed by millet-beans-cattle-chickens.

Portfolio	Expected return (TShs)	Risks (TShs)	CV
Maize, beans, cattle and sheep	382937.20	206574.40	0.54
Maize, sorghum, cattle and chicken	442307.60	221783.60	0.5
Millet, beans, cattle and chicken	240376.80	140229.20	0.58
Maize, groundnut, cattle and chicken	330034.00	175310.00	0.53
Maize, cowpea, cattle and goat	283015.20	157092.80	0.56
Maize, sunflower, cattle and goat	283541.60	156077.60	0.55
Sorghum, sunflower, cattle and goat	1129880.00	486694.40	0.43
Maize, pigeon pea cattle and sheep	140962.40	130660.00	0.93
Maize, green gram, goat and sheep	108776.80	106370.40	0.98
Maize, millet, cattle and goat	386227.20	204694.40	0.53

Table 5.
Expected returns and risks of potential crop-livestock portfolios.

Apparently, the high-return high-risk portfolio categories tended to include cattle and beans, which are high value commodities. However, these two commodities are sensitive to climatic shocks, especially droughts. Beans are the major source of food protein that are widely consumed and traded in both rural and urban areas of Tanzania. Beans from northern Tanzania are also exported to Kenya. Maize-green gram-goat-sheep and maize-millet-cattle-goat were the least-risk, lowest-return portfolios. Early maturing maize varieties, millet, and green gram are drought

tolerant and, hence, risk efficient. Likewise, goats are relatively less vulnerable than cattle. However, the downside risk associated with cattle is downplayed when this activity is part of the risk-efficient crop-livestock portfolios.

2.7 Conclusions and policy implications

Agro-pastoral households in the semi-arid areas of central and northern Tanzania have lived with the vagaries of weather, coping and adapting through an array of diversified crop and livestock portfolios. In the face of a changing climate, along with other production and market risks, current and potential crop and livestock portfolios must be empirically illuminated in order to test their underlying efficacy in ensuring acceptable returns and associated risks. Shedding light on the levels of returns and associated risks is critical in informing the future design of crop-livestock portfolios that enhance the livelihood resilience of agro-pastoral households in semi-arid areas of Tanzania.

The majority of agro-pastoralists are diversifying within and integratively across crop and animal farming activities. Some crops and livestock species, such as maize, cattle and sheep, are sensitive to climatic related production risks, but are widely raised. Apart from long-term breeding and genotype improvement programs to develop varieties and breeds that are drought resistant, the strategic reorientation of crop and livestock portfolios appears to be an affordable and tailored solution. For instance, goats and chickens that can thrive under critical drought conditions should be promoted in order to create portfolios that generate acceptable returns while minimizing risk.

Crop and livestock productivity in the semi-arid areas of central and northern Tanzania are generally low compared the national averages. Factors that contribute to such lower productivity among others include dependence on weather-dependent rainfed agriculture and lack of rainwater harvesting infrastructure. However, semi-arid Tanzania is home to a majority of the poor, with destitute cropping and herding families, thus making them poverty hotspots where poverty reduction efforts should be strategically targeted. Our analyses suggest an array of crop and livestock portfolios that can be promoted in order to generate economic returns within certain bounds of risks.

This study investigates the levels of economic returns and associate risks for the current and potential crop and livestock portfolios. In order to highlight the centrality of strategic choices of economic portfolios among agro-pastoralists for enhanced livelihood resilience, it is important to incorporate off-farm activities into the portfolio diversification analysis. However, this is left as an empirical niche for further studies.

Author details

Ponsian T. Sewando
Tengeru Institute of Community Development (TICD), Arusha, Tanzania

*Address all correspondence to: ponsiansewando@gmail.com

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