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Crop–livestock integration in smallholder farming systems of Goromonzi and Murehwa, Zimbabwe

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Abstract

Poor productivity in smallholder farming systems has necessitated research on the potential of crop–livestock integration to sustainably improve productivity. The study hypothesized that improvement in individual agronomic and livestock systems and synergistic utilization of by-products of either system increases productivity, profitability and integration. Smallholder farming households were classified into: old and resource endowed (*OR*); part time (*PT*); and young, risk-taking and enthusiastic (*YRE*) following a survey conducted in Murehwa and Goromonzi districts of Zimbabwe. Crop–livestock systems' integration scenarios were developed for each farmer category. Expression of crop–livestock integration in physical terms, e.g., kg ha^{-1}, can be complex and confounding, hence the expression of integration in monetary values. Baseline scenario results indicate that *OR* had the highest crop–livestock integration of $3981 compared with *PT* and *YRE* despite *OR* having the lowest manure usage compared with *PT* and *YRE* farmers. Moreover, *OR* had the least legume yields of <800 compared with 3530 kg ha^{-1} in *YRE* farmers. Subsequent crop–livestock integration scenarios increased maize grain yields by at least 50%, thus increasing profitability to $1210, $3230 and $3100 yr^{-1} for mucuna, cowpea and groundnut, respectively. Total income increased by 135, 132 and 101% translating to $9880, $2960 and $6290 yr^{-1} in *OR*, *PT* and *YRE* farmers, respectively. Crop–livestock integration therefore has the potential to improve smallholder crop and livestock productivity, variable with socio-economic status.

Introduction

Rapid population growth, climate uncertainty and food insecurity are key challenges facing smallholder farmers in sub-Saharan Africa (Mpande and Adziwa, 2011; Kassie *et al.*, 2012). Population growth and rapid urbanization have substantially increased the demand for crop and livestock products (Homann and Van Rooyen, 2007; Subhadra, 2007), and is projected to increase by as much as 70% by 2050 (Soussana, 2015). However, this demand might not be met because of the chronically poor crop and livestock production practices of smallholder farming systems in the region (Sánchez, 2010; Umar *et al.*, 2011; Nkomboni *et al.*, 2014).

Mixed crop–livestock production is the most practiced form of agriculture in smallholder farming communities of Zimbabwe (Mashingaidze *et al.*, 2012). The actual choice of crop–livestock activity combinations in a mixed farming system is dependent on local socio-economic and agro-ecological conditions such as soil, rainfall and temperature (Davendra, 2002). Household dynamics, farmer ingenuity, input and output market prices, political stability and technological developments also influence the choice and components of mixed farming systems (Schiere and Kater, 2001; Kindu *et al.*, 2014).

Mixed crop–livestock farming systems lead to diversification which improves farm productivity, minimize production and economic risks, and buffering against climate variability (Van Keulen and Schiere, 2004). The livestock component acts as alternative security, savings and investment options in smallholder farming systems (Kurosaki, 1997). Crop–livestock integration has the potential to improve sustainable intensification of crop and livestock productivity (Sempore *et al.*, 2016). Crop–livestock integration involves intensifying the interaction between crops and livestock in a single farming unit in order to improve the combined productivity of the individual components of the system and minimize use of external inputs (Mohammed-Saleem, 1995; Williams *et al.*, 1999). Crop–livestock integration could be one of the first steps to improve sustainability of smallholder mixed farming systems, which have been consistently plagued by low productivity and profitability (Wolmer, 1997). It also minimizes crop production costs through use of manure and draught power. Use of crop residues improves livestock condition during drier seasons (Sempore *et al*., 2016). Smallholder farmers have always practised some form of mixed farming and the systems have been poorly integrated. Low integration has been attributed to increased land pressure, poor markets, limited ease of practice and low transfers between crops and livestock (Blackburn, 1998). Such farming systems also demand more labor in manure handling, initial capital investment and have less economies of scale. They also potentially lead to conflicts, competition for resources and land degradation if poorly managed (Van Keulen and Schiere, 2004). Large-scale commercial farmers do not use mixed farming systems due to the longer 'gestation period' of the benefits and due to specialization (Sempore *et al*., 2016).

Irrespective of their huge potential, mixed farming systems often suffer from recurrent low productivity due to competition for resources and the need to couple knowledge on both crop and livestock which, in most cases, is difficult for a farmer to do on their own (Blackburn, 1998; Kindu *et al*., 2014). It can be argued that the smallholder farming systems have not benefitted from crop–livestock integration. The major challenge being lack of demonstrated knowledge and potential of crop–livestock integration in smallholder setups in understandable and measurable form such as monetary value. However, demonstration of the benefits of crop–livestock integration is often limited by the cost of on-farm demonstrations and experimentation. There is a need for a cost-effective method to demonstrate the benefits of crop–livestock integration in smallholder systems (Wolmer, 1997).

The Food and Agriculture Organization (FAO) has described *integrated* farming systems as systems where crop and livestock are highly dependant on each other and products or by-products of each of the components are inputs of the other (FAO, 2001). Sempore *et al*. (2016) similarly suggest that integration involves the transfer of products between crop and livestock within the same land area. This involves, for example, draught power for cultivation, fodder from crop residues and fodder crops and organic manure from livestock waste and crop residues (Sempore *et al*., 2016). According to Parsons *et al*. (2011), this also involves feeding of animals with at least 10% of crop residues and maximization of the use of animal products in crop production and *vice versa* (Chipunza *et al*., 2013). Wolmer (1997) highlights the potential to assess crop–livestock on the basis of the energy and nutrients interchanged between crop and livstock systems. Research on crop livestock integration in West Africa has led to an increase in the amount of crop residues fed to livestock (Sempore *et al*., 2016). Studies of crop–livestock integration in smallholder dairy farming and beef systems have indicated positive results, with the assertion that marketing is important for the uptake and enhanced impact of integrated crop–livestock integration strategies in smallholder systems (Gwiriri *et al*., 2016). Despite these studies, adoption of crop–livestock integration strategies is still low, which has been attributed to lack of clear demonstration of the benefits of appropriate crop–livestock integration. Low adoption has also been due to the assumption that smallholder farmers are a homogeneous group, hence blanket recommendation of crop–livestock integration strategies (Sempore *et al*., 2016).

The challenges facing smallholder farmers call for urgent multi-disciplinary strategies to increase the productivity and profitability options associated with integrated crop–livestock systems (Blackburn, 1995). Due to the different abilities of farmers to sustainably use technologies, categorizing farming households increases our understanding of the diversity and homogeneity of the smallholder farmer population. Use of farmer typology profiling is essential in disaggregating and understanding the diversity among smallholder farmers (Chikowo *et al*., 2014). This is a key in the development of banded policies and the development of corresponding solutions to their farming challenges (Tshoni, 2015). Compared with the zoning technique, the typology approach provides a practical method of capturing farmer diversity and farming systems producing qualitative outputs for evaluation of developmental pathways and policy formulation. This reduces the tendency to offer blanket recommendations to challenges facing smallholder farmers and it increases the potential for the adoption of recommended interventions (Chikowo *et al*., 2014). In each case of crop–livestock integration, synergism can be further increased by adoption of enterprise-specific interventions that favor the performance of the system's component enterprises.

These assertions could be verified through use of traditional on-farm trials which have been widely used to provide agronomic solutions to challenges facing farmers (Maat, 2011). The use of on-farm field trials is however usually expensive, time consuming and complex in most instances (Jones *et al*., 2003). The use of simulation models is relatively easier, less time consuming and practical in assessing crop–livestock integration options among smallholder farmers. Models like the Agricultural Production Simulator (APSIM) (Holzworth *et al*., 2014), Integrated Analysis Tool (IAT) (Lisson *et al*., 2010) and APSFARM have been extensively used in cropping systems (Masikati *et al*., 2014), household and multi-disciplinary socio-economic modeling (de Voil *et al*., 2009).

The current study sought to use simulation models to assess the effect of improved crop and livestock production technologies on crop and livestock productivity, profitability and integration in smallholder farming systems under sub humid conditions of Zimbabwe. We hypothesized that if smallholder farmers use improved agronomic and livestock husbandry practices, crop and livestock product yields will increase, resulting in higher household productivity, profitability and integration. Specific objectives were to (a) assess the prevailing levels of crop and livestock integration in Murehwa and Goromonzi districts, Mashonaland East province, Zimbabwe (Supplementary Fig. S1), (b) use APSIM and IAT modeling tools to assess the effect of improved productivity of crop and livestock enterprises; the contribution of crops to the livestock enterprise and *vice versa*; and on the overall household income generation.

Materials and methods

Study area

The study was undertaken within a larger ACIAR-funded research project '*Integrating crop and livestock production for improved food security and livelihoods in rural Zimbabwe*' (ZimCLIFS). The project sought to improve food security through improved integration of crop and livestock production in Mashonaland (Murehwa and Goromonzi) and Matabeleland (Nkayi and Gwanda). This study is focused only on Murehwa and Goromonzi districts located in the sub-humid part of Zimbabwe.

On-farm experimentation with a range of crop–livestock integration practices was conducted in Murehwa and Goromonzi districts of Mashonaland East province in Zimbabwe. Murehwa is located at 17.65°S; 31.78°E at 1300 m above sea level (Supplementary Fig. S1). Goromonzi is located at 17.86°S; 31.22°E at 1462 m above sea level. Both districts are located in agro-ecological region II which covers 8% of Zimbabwe[1] and receives an average rainfall ranging between 750 and 1000 mm per annum with 16–18 rainy pentads per season received between October and May (Mugandani *et al*., 2012). The dominant soil type in both Goromonzi and Murehwa are low fertility sands derived from granitic parent material. There are however sporadic patches of fertile clay derived from dolerite parent material (Nyamapfene, 1991). The research covered both Murehwa and Goromonzi districts which have similar agro-ecological conditions, thus there is similar agricultural productivity and socio-economic conditions. Similarly, it is assumed that there will be no significant differences in the crop and livestock productivity (Mugandani *et al*., 2012).

Most of the households in the two districts practice mixed farming with maize (*Zea mays* L.) and cattle (*Bos indicus* L.) being the dominant crop and livestock species. Households also grow groundnuts (*Arachis hypogaea* L.), cowpeas (*Vigna unguiculata* L. var. Walp) and sweet potatoes [*Ipomoea batatas* (L.) Lam.]. Goats (*Capra hircus* L.) and traditional chickens also contribute to the livestock component of many smallholder farms (Mutenje *et al*., 2014). Some households in Murehwa and Goromonzi practice market gardening, and sell vegetables (*Brassica* spp.), tomatoes (*Lycopersicon esculentum* L.) and sweet potatoes at the Harare vegetable market (Mpande and Adziwa, 2011).

Under the local communal land tenure system, cattle are usually herded during the rainy season to avoid crop damages in the fields, and are confined to kraals near the homestead for protection during the night (Abunyewa and Karbo, 2005; FAO, 2006). During the dry season, animals graze freely and are occasionally checked for diseases, injuries or losses. During such periods, cattle graze on crop residues left in the fields after harvesting and most of the manure that accumulates in the kraals is applied to the vegetable plots (Nzuma, 2013). The bulk of the feed resource for smallholder cattle during the dry season is communal rangelands, which are poor in feed quality and quantity, thus negatively affecting productivity (Gwiriri *et al*., 2016).

Baseline survey and farmer classification

A total of 800 households were sampled from both Murehwa and Goromonzi districts of Mashonaland East province. A structured household questionnaire was administered to a statistical sample of ten household heads. The questionnaire collected data on household demography, asset ownership, crop and livestock dynamics, household economics and crop and livestock marketing information (Mutenje *et al*., 2014). The household survey data were subjected to principal component analysis (PCA). PCA is a tool for assessing diversity in a population. PCA identified the key patterns among the respondent farmers to classify them into different categories. PCA aggregates characteristics of farmers into different clusters based on the predominant characteristics of the farming systems. The following three farmer categories were identified: (1) *old resource endowed* (OR); (2) *part time* (PT); and (3) *young, risk taking and enthusiastic* (YRE) (Table 1). Chikowo *et al*. (2014) categorized farmers similarly in their studies. During the project, one representative household that had adopted some form of crop–livestock integration practices was randomly selected for the case study from each of the ten ZimCLIFS project communities in Mashonaland East. This increases the chances of capturing all sources of diversity in the two districts. Household selection was conducted with assistance of the resident Agricultural Extension Officers (AEOs) in each project community. Selection criteria included willingness of the farmer to host on-farm trials, presence of both crop and livestock production activities on the farm and possession of unused land area on which to expand agricultural activities. The farmer representatives were then allocated into the relevant farmer categories obtained through PCA analysis (Table 1).

OR farmers are usually retired civil servants or former low-level private sector employees. These farmers possess greater land holdings, own more livestock, cultivate a variety of crops and generally have more accumulated financial resources. They also use more agricultural inputs but have less available household labor. *PT* farmers are mostly urban dwellers who have rural homesteads which they visit during the weekends and employ laborers who are mostly in charge of farming operations in their absence. These farmers have the least available land area and crop and livestock farming experience. *YRE* farmers are typically <40 years of age and are financially insecure, but have a genuine passion for farming and are willing to try new farming technologies (Table 1). Each category comprised of small-scale farmers with diverse characteristics, but the study focused on farmers with the most predominant characteristics, which was used to define each group. Using these farmer categories, a modeling-based case study approach was employed to assess the effect of improved crop–livestock integration on smallholder farms within the ZimCLIFS project communities.

The concept of crop–livestock integration

Expression of crop–livestock integration in physical terms such as kg ha^{-1}, liters, livestock units (LU), labor hours and oxen days can be complex and confounding, hence the expression of integration in monetary values was adopted for the current study. Monetary value allows for easy comparison and understanding for smallholder farmers. Expression in monetary value aid in adoption of crop–livestock integration strategies as farmers are increasingly attracted by financial returns. Conceptually, integration can be expressed in monetary terms[2] as the 'additional *gross margin (GM)*'[3] that is derived from the synergism of coupled crop–livestock production activities *vs* individual separate crop and livestock entities. In this study, crop–livestock integration was computed as the total monetary value of products interchanged between the crop and livestock components (Sempore *et al*., 2016). The monetary value of crop products such as fodder and crop residue was computed using actual production cost estimates from the farmers who produced the crop products. Similarly, the total monetary value of livestock products such as draught power and manure utilized or consumed by crops was computed. Current market values were used in assessing the value of the crop and livestock products and by-products.

Profitability assessment was conducted among each of the three farmer categories using the IAT (Lisson *et al*., 2010). The model computed profitability as the difference between value of inputs and outputs. The study assumed that some profits from the enterprises will be utilized as the household income. It is also typical of households to utilize profits for financing household operations (Mutenje *et al*., 2014).

[1]Zimbabwe is separated into five broad agro-ecological regions which are classified by various climatic and resource factors for their suitability for various agricultural production systems (Mugandani *et al*., 2012).

[2]All currency values are expressed in US$.

[3]Gross margin=total revenue from crop and livestock produce sales less direct production and marketing expenses.

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Table 1. Key characteristics of the dominant smallholder farmer categories in Murehwa and Goromonzi districts, Mashonaland East province, Zimbabwe

Characteristic	Old resource endowed	Part time	Young, risk-taking and enthusiastic
Age of household head (years)	58	50	39
Education years	12.50	11	11
Household size	3	5	8.70
Household asset index	1.03	0.96	0.77
Cropping experience (years)	36	17	15
Livestock experience (years)	31	13	10
Cattle total (livestock units/yr)	12.85	5.45	10.27
Goats total (goat units/yr)	0.42	0.19	0.12
Off-farm income (US$/yr)	1575	970.75	150.0
Farm income (US$/yr)	1460	2114	4827
Arable land (ha/yr)	2.30	0.90	1.70
Basal fertilizer (kg/farmer/yr)	722	304	597
Top dressing (kg/farmer/yr)	671	158	403
Land under groundnuts (ha/yr)	0.24	0.11	0.04
Land under maize (ha/yr)	0.66	0.61	0.73

Crop–livestock integration scenarios

Several crop and livestock production scenarios were formulated for each farmer category that were judged by the authors to be technically feasible for improving crop–livestock integration for specific smallholders (Table 2). Each of the scenarios was formulated based on resource endowment, literacy levels and challenges in current crop–livestock production of the targeted groups. Resource endowed farmers were designed scenarios that need financial resources. With regards to semi-literate farmers, the scenarios were designed to mimic agricultural advice which came from AEOs. Scenarios for the young resource endowed farmers were designed to mimic advice from AEOs for rationale crop and livestock husbandry practices and their eagerness to undertake novel farming practices.

Simulation models

The prospective production and financial implications of adopting the various crop and livestock integration strategies were explored using simulation modeling. Crop yields (grain, stover and forages) were projected using the APSIM (Holzworth *et al.*, 2014) and these data were then used to calibrate the IAT (Lisson *et al.*, 2010), a farm household-level farming systems performance evaluation model.

APSIM is a longstanding biophysical cropping systems model that simulates crop yields and biophysical processes through integrating crop, soil, climate and management parameter interactions (Keating *et al.*, 2003). The APSIM model has been extensively used in soil water balance (Verburg and Bond, 2003; Mupangwa and Jewitt, 2011), soil nutrient dynamics (Shamudzarira and Robertson, 2002; MacCarthy *et al.*, 2010; Masikati *et al.*, 2014), climate change (Kandji *et al.*, 2006; Cooper *et al.*, 2008; Dimes *et al.*, 2008) and in mixed crop–livestock systems (Lisson *et al.*, 2001) research within the sub-Saharan region. APSIM is a biophysical crop model, hence it cannot simulate socio-economic aspects such as resource endowment. However, the model can indirectly account for resource endowment through fertilizer dynamics. Resource endowment will lead to increased availability of income to purchase mineral fertilizers. This is because farmers have highlighted that reduced input use is attributed to financial challenges (Thomas *et al.*, 2007). The model was therefore parameterized with high fertilizer application (Holzworth *et al.*, 2014). In this research, the APSIM model was calibrated for the climate, soil, crop variety and agronomic conditions of each of the cultivated crop types during the 2012/13 and 2014/15 cropping seasons. Calibration of the APSIM model indicated n-RMSE values for crop yields and stover of <30% across all crop types and farmers' categories. Therefore, the APSIM model was assumed to predict yields accurately (Manuela *et al.*, 2007). In this research, the APSIM model was used to simulate grain yields and stover of all crops cultivated by the three farmer groups (Table 1).

The IAT employs a modular approach that combines crop and forage databases with an animal production simulation model and a household economic module to explore the resource and financial impacts of changes to crop and livestock production activities embedded within smallholder mixed crop–livestock farming systems. The model simulates enterprise, household and whole farm profitability, labor, food security based on crop yield, land area, household and labor dynamics, input and output prices. The model integrates the household financial and demographic dynamics, crop, labor, animals and pastures to evaluate their combined impact on household food security and profitability (Lisson *et al.*, 2010). The IAT model has been extensively used in crop livestock systems in Indonesia (Lisson *et al.*, 2001) and improved Bali cattle productivity (MacLeod *et al.*, 1999). The IAT model was utilized to assess the profitability of the different maize and livestock enterprises among the different farming categories.

Crop management

The APSIM model was parameterized based on the crop management and agro-ecological condition data of Murehwa and

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Table 2. Farmer category-specific crop–livestock improvement and integration scenarios for farmers in Murehwa and Goromonzi districts, Zimbabwe

Farmer type	Old resource endowed	Part time	Young, risk-taking and enthusiastic
Land area (ha)	5.75	2.25	2.0
Crop production scenarios	• Increase maize area from 1.7 to 2 ha	• Reduce maize area from 1.2 to 1 ha	• Increase area under maize from 0.85 to 1.2 ha
	• Improved agronomy (plant population, recommended fertilization and improved varieties)	• Improved agronomy (plant population, recommended fertilization and improved varieties)	• Improved agronomy (plant population, recommended fertilization and improved varieties)
	• Increase groundnut area from 0.6 to 1 ha	• Increase area under groundnut a cash crop from 0.1 to 0.4 ha	• Increase groundnut area from 0.1 to 0.23 ha and apply 200 kg ha^{-1} gypsum
	• Value addition to groundnuts through shelling and selling grain resulting in increased grain selling price from US $0.2 to US$0.9 kg^{-1}.	• Value addition to groundnuts through shelling and selling grain resulting in increased grain selling price from US $0.2 to US 0.9 kg^{-1}.	• Value addition to groundnuts through shelling and selling grain resulting in increased grain selling price from US $0.2 to US$0.9 kg^{-1}
	• Introduction of herbicides and reduction hired labor for weeding from to 8 labor days	• Increase area under supplementary feed source mucuna from 0.2 to 0.25 ha	• Reduce fertilizer use in cowpea from 500 to 300 kg ha^{-1}
	• Reduce sorghum area from 0.13 to 0.1 ha		• Introduce mucuna at 0.23 ha
	• Increase mucuna area to from 0.13 to 0.3 ha		• Introduce lablab at 0.23 ha
	• Reduce lablab area from 0.3 ha to 0.2 ha		
Livestock production scenarios	• Supplementary feeding of draught stock, sale stock and breeding animals	• Supplementary feeding of cattle	• Supplementary feeding of draught stock, sale stock, breeding animals
	• Increase number of animals sold from one to three per year	• Supplementary feeding of goats and sale four goats per year	• Increase number of animals sold to two from one per year
	• Improved cattle marketing – taking animals to commercial abattoirs	• Increase number of indigenous chickens sold from 15 to 25 per year	• Improved cattle marketing through slaughtering at commercial abattoirs
			• Sale one goat per year

Goromonzi districts. The model was calibrated for both the baseline and simulated crop management scenarios (Supplementary Table S1). For the baseline scenario, the crop management decisions were not uniform within and between the different smallholder farmer categories but overall they were lower than the recommended. Farmers applied relatively low fertilizer levels and had low plant populations. For the simulated scenarios, it was assumed that the fields were insect pest and disease free.

Statistical analysis

GenStat 14.1 (VSN 2002) was used to perform a Residual Maximum Likelihood (REML) assessment of whether crop grain and stover yields differ significantly across the different scenarios, farmer categories and crop types. Grain and stover yields were the main response variables while farmer categories and crop types were the fixed effects. The REML approach was used because the data were unbalanced due to farmers having cultivated different crop types. Means of grain and stover yields of different crops were separated through the Least Significant Difference (LSD) test ($P \leqslant 0.05$).

Results

Initial crop–livestock integration on smallholder farms

The initial assessment showed that *OR* farmers had the highest level of crop–livestock integration with a total monetary value of \$3981 yr^{-1}. The *PT* and *YRE* farmers had relatively lower integration with monetary values of \$1487 yr^{-1} and \$2872 yr^{-1}, respectively (Table 3). At least 50% of the crop–livestock integration balance was derived from crops to livestock as opposed to

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Table 3. Monetary value of the contribution of crops–livestock and livestock–crops under the baseline scenario (US\$ yr^{-1}) in Murehwa and Goromonzi districts, Mashonaland East province, Zimbabwe

Item	Farmer category		
	Old resource endowed	Part time	Young, risk-taking and enthusiastic
Maize	299	436	200
Groundnuts	359	421	767
Bambaranuts	359		526
Cowpea	829		
Millet		71	
Mucuna	556		
Lablab	576		
Soybeans			268
Total economic value of cropping to livestock systems (US\$ yr^{-1})	2976	857	1832
Total oxen days (oxen days)	20.7	5	8
Manure quantity (kg)	4800	6000	10,000
Total economic value of oxen days (\$ yr^{-1})	621	150	240
Value of manure (\$)	384	480	800
Total economic value of livestock to cropping systems (US\$ yr^{-1})	1005	630	1040
Total economic value of crop–livestock integration system (US\$ yr^{-1})	3981	1487	2872

livestock to crops. It can be noted that the contribution of crops to livestock varied with farmer category with the *OR* farmers having the highest contribution of the three classes. *YRE* farmers had a relatively lower contribution of US\$1832 yr^{-1} but *PT* farmers had the lowest contribution of crops to livestock. The contribution of crops to livestock among the *OR* farmers was dominated by cowpea, lablab (*Lablab purpureus* L.) and velvet bean (*Mucuna pruriens* L.) and the lowest individual crop to livestock contribution was from maize at \$299 yr^{-1}. However, maize had the highest crop to livestock contribution at \$436 yr^{-1} among *PT* farmers. While maize had the least crop to livestock contribution of \$200 yr^{-1}, groundnuts had the greatest component of crop to livestock contribution of US\$767 yr^{-1} in the YRE farmers (Table 3).

As observed with crop contribution to livestock, initial livestock contribution to crops was variable between the classes, but with some degree of similarity between the *OR* and *YRE* farmers. *PT* farmers had the least livestock to crop contribution compared with *OR* and *YRE*. Manure contributed at least 30% of the livestock to crop contribution, contributing 38% among OR farmers and an equivalent of 76% among *PT* and *YRE* farmers, although notably the actual annual contribution value in *YRE* (US\$800) was almost double that for the *PT* farmers (US\$480). However, *OR* had the highest draught power usage and *PT* farmers the least (Table 3).

Simulated individual crop and livestock enterprise profitability

The baseline survey indicated that the *OR* farmers had a net profit of at least \$5500 yr^{-1} with the bulk of it being contributed by cattle, maize and cowpea (Table 4). The lowest GMs were derived from sorghum and common beans with <\$50 yr^{-1}. After simulating future crop yields and profitability based on the agronomic and livestock improvement scenarios, overall profitability increased to at least \$15,200 yr^{-1} for *OR* farmers. Maize, groundnuts and cattle had the highest simulated individual GMs. Sorghum, common beans, cowpea and chickens had the lowest GM and contributed the least to the total profit with each component contributing <\$800 yr^{-1}. The highest increase in profitability was derived from groundnuts, common beans and goats. For the *PT* farmers, the baseline survey indicated a net profit of \$1510 yr^{-1}. The largest contribution was from chickens and ducks. *PT* farmers experienced losses in cowpea and had no gains in groundnuts and goats. Crop and livestock production improvement options increased net profit by over 280%, up to \$4250 yr^{-1}. There was increased income from maize and cattle, while ducks and chickens remained unchanged (Table 4).

The *YRE* farmer baseline survey results indicated a net profit of approximately \$1460 yr^{-1} with the bulk of it coming from maize, chickens, cattle and bambaranuts. They however experienced losses in cowpea. Upon imposition of crop and livestock improvement scenarios, *YRE* farmers achieved a 325% increase in net profit, attaining at least \$4750 yr^{-1}. Groundnuts, cowpea, cattle and goats enterprises had the greatest improvement in profitability (Table 4).

Simulated crop–livestock integration

After applying the crop and livestock improvement scenarios with the calibrated APSIM and IAT models, there was a projected overall increase in the contribution of crops to livestock in all farmer categories. The *OR* farmers realized at least a 140% increase in crop contribution to livestock, while the *PT* and *YRE* farmers, respectively, realized a 130 and 100% increase in crop contributions toward livestock. Legume crops made a higher crop contribution to livestock than cereals (Table 5).

Under the improved livestock management scenarios applied to all farmer categories, there was an increase in the contribution of livestock to crops of 190% (US\$2890 yr^{-1}), 55% (US\$980 yr^{-1})

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Table 4. Baseline and simulated crop and livestock contributions to income ($) in all farmer types from Goromonzi and Murehwa districts, Zimbabwe

Farmer category	Enterprise	Baseline	Simulated
Old resource endowed	Maize	1280	2930
	Groundnuts	−120	3440
	Cowpeas	690	750
	Sorghum	40	210
	Common beans	30	2550
	Mucuna	–	210
	Lablab		120
	Cattle	2670	3740
	Goats	110	870
	Chickens	390	390
	Broilers	420	420
	Net profit ($)	5510	15,630
Part time	Maize	90	860
	Groundnuts	0	160
	Cowpeas	−70	80
	Cattle	300	1690
	Goats	0	270
	Chickens	830	830
	Ducks	370	370
	Net profit ($)	1510	4250
Young, risk-taking and enthusiastic	Maize	480	980
	Groundnuts	−10	550
	Cowpeas	−4	30
	Bambara nuts	150	0.00
	Mucuna		80
	Lablab		110
	Cattle	380	2270
	Goats	20	480
	Chickens	450	460
	Net profit ($)	1460	4970

A negative figure indicates that the enterprise experienced a net loss and a positive figure indicates that the enterprise experienced a profit.

and 150% (US$2600 yr^{-1}), respectively, for the *OR*, *PT* and *YRE* farmers. The economic value of oxen days (draught) also increased considerably compared with the baseline scenario. It is noted that the contribution value of crops to livestock was much higher than the reverse, with crop to livestock contribution being approximately 313% higher than livestock to crop contribution for the *OR* farmer category.

Discussion

Before attempting to evaluate crop–livestock integration, the study assessed the degree of diversity among the small-scale farmers in the Murehwa and Goromonzi districts. Generally, farmers currently experience relatively poor productivity in their farming systems.

Despite the wide array of recommendations for improving productivity, the uptake of the recommendations has been poor and the effectiveness is highly variable. Options to increase productivity differ among the different individual farmers. Twomlow *et al.* (2008) highlight the use of blanket recommendations ignoring the underlying socio-economic and cultural aspects as the leading cause of poor adoption. This therefore justifies the need for assessment of diversity among farmers prior to proposing recommendations. There is therefore a need for proposing recommendations that correspond to the farmer's socio-economic characteristics. The current study realized significant diversity among the different small-scale farmers in the form of old and resource endowed (*OR*), part-time (*PT*) and young and resource endowed (*YRE*) farmers. There is a significant variation of the socio-economic characteristics among the different farmer categories. This therefore justifies the use of different crop–livestock integration strategies in different farmer categories to improve effectiveness of uptake of the different crop–livestock integration recommendations.

Crop–livestock integration varied among the different farmer categories. Integration was greater in *OR* followed by *YRE* and *PT* farmers. High levels of integration are attributed to many factors including farming experience and the use of livestock manure. The greater crop–livestock integration among *OR* farmers can largely be attributed to the high level of experience of at least 30 years in both crop and livestock production technologies. Due to greater experience smallholder farmers acquire and perfect skills to increase productivity while minimizing external input. This was in sharp contrast to the relatively low farming experience of 10 and 17 years for the *PT* and *YRE* smallholder farmers, respectively (Table 1). That is, the *OR* farmers had greater knowhow in terms of increasing the efficiency and productivity of their farming systems, especially the different systems' components (Sombilla *et al.*, 2000). *PT* farmers have alternate sources of income, hence they are not motivated to invest in crop–livestock integration strategies to improve productivity. The extra labor and knowhow needs may demotivate *PT* farmers from cultivating forage for livestock feeding for sell. A higher initial level of crop–livestock integration was evident with *OR* farmers, their crops contributing more income than livestock. The use of legume crops through grain and residues fed to livestock contributed at least 90% of the total crop value, although the yields are evidently low, which is a general characteristic of many smallholder farming systems. This can be attributed to the higher market value and quantity of legume grain and residue relative to cereals. For instance, legumes have a high grain content of at least 20–40% of their total dry weight compared with <10–12% in cereals (Shewry and Halford, 2015). Besides the physiological aspect that proteins require more energy of at least 50,000 kJ mol^{-1} compared with the 2868 kJ mol^{-1} required for carbohydrate production (Luley-Goedl and Nidetzky, 2010), the production costs of legumes are higher than for cereals, which translated to the higher value of contribution of crops to livestock.

Livestock manure utilized in crop fields and draught power for crop cultivation and household transport were the most significant livestock-to-crop contributions across all three farmer types. The highest values for livestock contribution to crops was recorded for the *OR* farmers, and is attributed to the greater number of livestock holding in the *OR* farmer category, averaging 12.85 LU and 0.42 goat units (GU) compared with 5.45 and 10.27 LU among the *PT* and *YRE* farmers, respectively. In

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Table 5. Total monetary value of the contribution of crops to livestock under improved options among smallholder farmers Murehwa and Goromonzi districts, Mashonaland East province, Zimbabwe

		Farmer category	
Item	Old resource endowed	Part time	Young, risk-taking and enthusiastic
Maize	370	370	370
Groundnuts	1000	420	1000
Bambara nuts	550		550
Cowpea	1200	1200	1200
Beans	1160		
Millet			570
Mucuna	1240	250	650
Lablab	1480		720
Total economic value of cropping to livestock systems (US$ yr^{-1})	7000	2240	4870
% Increase in value from baseline	140	130	100
Total oxen days (oxen days)	21.5	5.8	11.8
Manure quantity (kg)	28,000	10,000	28,000
Total economic value of oxen days ($ yr^{-1})	650	170	350
Value of manure ($)	2240	800	2240
Total economic value of livestock to cropping systems (US$ yr^{-1})	2890	980	2600
% Increase in value from baseline	190	60	150
Total economic value of crop–livestock integration system (US$ yr^{-1})	9890	3220	7470

addition, most of the *OR* farmers were at least 58 years old, are retired government employees who once had relatively high-income jobs and had more disposable income and savings invested in cattle. The greater LUs also enabled *OR* farmers to be better positioned to increase crop livestock integration, through provision of manure to crops. On the other hand, the *PT* farmers were relatively young and <50 years of age, hence have less disposable income with which to acquire livestock (Parkinson, 2009). On the contrary, the *YRE* farmers were <39 years of age, but were noted to be shrewd and full-time farmers, and this may explain their relatively higher livestock numbers.

The lowest level of integration was observed for the *PT* farmer category who had a crop-to-livestock and livestock-to-crop contribution of \$860 and \$630 yr^{-1}, respectively (Table 3). These farmers allocate less time to farming and hence attain lower crop yields and less income. The low LU associated with these farmers might also be attributed to poor livestock management reflected in the low manure use and value of draught power.

Optimization of crop yields

Despite having greater crop diversity, crop yields for the *OR* farmers were generally low, with legumes having the lowest yields. Similarly, among the *PT* and *YRE* farmers, legumes had the least yields compared with other crop types. This is attributed to poor agronomic practices on smallholder farms especially in legumes. Legumes are often seeded late and at low plant populations with little or no fertilizer or manure applied. In addition, *OR* farmers were observed to use retained legume seed due to relatively high legume seed prices (up to \$5 kg^{-1}) compared with maize seed prices (~\$2 kg^{-1}) (Akibode and Maredia, 2011). Farmers across all three categories generally perceive legumes as secondary crops, hence the amount of investment in them is low (Giller *et al.*, 2011) resulting in low legume yields obtained in the current study compared with yields obtained in commercial systems.

The low crop yields for the *OR* farmer category could also be attributed to the limited availability of household labor (about two aged adults per household) that is characteristic of this category. Labor shortages are more critical during the peak labor demand periods where high weed pressure in multiple crops will lead to significant yield penalties for the *OR* farmer category. The effect of a labor shortage is less relevant for the *YRE* farmers category who have greater available household labor of eight persons, allowing for faster and timeous weed control.

PT farmers spend most of their time engaged in off-farm activities, as they only cultivate two crops compared with the *OR* and *YRE* farmers who cultivate multiple crops. This resulted in less time and labor allocated to on-farm activities, which was exacerbated by the limited land area of ~2.3 ha. Off-farm activities like cutting firewood, fishing and industrial jobs by *PT* farmers result in increased available capital to purchase inputs like fertilizers. This resulted in increased fertilizer use of at least 200 kg ha^{-1} basal dressing and 300 kg ha^{-1} top dressing among part-time farmers which complies with the generally recommended fertilizer rates (Seed Co., 2010).

The *YRE* farmers had relatively higher legume yields due to the use of relatively small quantities of basal fertilizer in some of the legume crops. This promoted better legume growth and development leading to higher yields. The risk taking, ingenuity and inquisitive mentality and attitude of this farmer type often leads them to applying fertilizers in legumes. This also enables them to cultivate a variety of crops despite their limited financial resources. However, use of retained legume seed, late sowing and poor soil fertility management are among the leading causes of poor legume yields in the smallholder farming sector (Giller *et al.*, 2011). Legume yields are rarely above 500 kg ha^{-1} under smallholder farming. Improved agronomic practices through the use of better hybrid varieties at correct plant population can increase yields to commercial levels (Seed Co., 2010). This is reflected in the simulated improved crop yields across all three farmer types with the *OR* and *YRE* farmers recording the higher yield increases.

Livestock manure

Despite their higher livestock holdings, the *OR* farmers used the least amount of manure (<5 t ha^{-1} yr^{-1}) compared with the *PT* and *YRE* farmers. While the greater number of cattle would imply that the *OR* farmers have high available quantities of manure to use, manure collection, transport and application require access to labor. The reduced household labor associated with the *OR* farmers may well account for the limited use and application of manure in their fields. High manure usage by the *YRE* farmers' category might be attributed to the lack of disposable cash to purchase mineral fertilizer, hence management to improve soil fertility was mainly through manure use.

Simulated maximum utilization of livestock manure would reduce mineral fertilizer use across all three farmer types. Based on their livestock numbers, the *OR* farmers can apply at least 32 tonnes of manure which is sufficient to fertilize a hectare and improve maize productivity. In contrast, the *PT* farmers who have 5.45 LU can only apply a maximum of 14 tonnes of manure which is insufficient to fertilize a hectare of crop. Lack of mineral fertilizer subsidies in Zimbabwe as a result of macro-economic challenges also translates to a higher premium being placed on manure which, in turn, makes it an expensive commodity to purchase off-farm (Wolmer, 1997). Farmers are therefore motivated to pen livestock during the night to enable them to collect more manure.

Crop residue use on smallholder farms

There is competition for stover in mixed smallholder farming systems. Livestock consume crop residues during the dry season, but crop residues are also applied as mulch in the field. The competition is exacerbated by the fact that crop residues have always been in short supply due to poor crop residue productivity in smallholder farming systems. As a result, the baseline use of crop residues for livestock production was <30% across the three farmer types. This is less than the recommended threshold of at least 30% crop residue cover. In smallholder systems, residues are utilized as mulch, in compost preparation, burnt or blown away by wind. This corresponds with the findings by Russo (1988) where observation of local practices revealed that some farmers burn their crop residues after harvest or utilize them to making compost rather than keep for livestock feed. There is therefore a deficit in crop residues for use as either supplementary stock feed or mulch in smallholder farming systems. The bulkiness of whole maize crop plant culminates in substantial transport costs for off-field processing, hence maize is normally processed in the field. As a result, residues remain in the field and some are consumed by cattle in unfenced fields. Maize crop residues are the most common source of alternative livestock feed during the dry season in smallholder farming systems. Maize crop residues, however, have poor nutritional value with a crude protein content of 5.1% CP (Lazzarini *et al.*, 2009). It can be argued that maize crop residues have better value when utilized as mulch, as opposed to stock feed. Crop and forage legumes are potential alternatives to maize crop residues as they have better nutritive value. This therefore increases the contribution of crops to livestock, thus improving integration.

Cattle normally feed on veld grass with a low crude protein content of 4% CP whose quantity and quality reduce during the dry season. The low baseline land area traditionally allocated to cultivating legumes reduced the amount of legume residue available for livestock. Improvements in agronomic practices and efficient use of residues could increase grain and biomass yields, thus increasing the amount of legume residues available for livestock feeding (Giller *et al.*, 2011).

Forage and fodder legumes have a relatively high grain and residue CP content of at least 17%. It has been asserted by Gwanzura *et al.* (2012) that velvet bean and lablab, low fiber legumes which have a crude protein content range of 16–19%, can be utilized to supplement low-quality roughages such as grass and maize crop residue resulting in improved ruminant productivity. Under the scenarios in which all available crop residues were used for feed, the level of livestock productivity increased (Table 1). *OR* farmers had access to the highest quantities of forage. However, limited availability of land and time resources of the *PT* farmers reduced the benefits that they could obtain from improved agronomic practices as the projected yield increases were minimal.

Profitability of crop and livestock production enterprises

The relatively low profits of \$1510 yr^{-1} in the *PT* farmer type category before adoption of improved crop–livestock production technologies can be attributed to the reduced profits from maize and goat enterprises, and was worsened by losses in groundnut production (Table 4). The relatively high contribution to profits associated with chickens and cattle reinforce the fact that livestock may still perform relatively well despite limited management as typified by no use of supplementary feed and the free ranging system of grazing that is associated with labor-constrained households typical of *PT* farmers. This is also typical of *OR* and *YRE* farmers who receive at least 50% of income from chickens and cattle.

The higher projected profits that could be derived from the adoption of improved maize growing practices across all farmer types contrast with national trends in Zimbabwe which show recurrent maize losses. This can be attributed to the use of recommended agronomic farming practices across all farmer types. Specifically in *PT* and *YRE* farmers, this prospective gain can be attributed to the increased basal and top dressing fertilizer use to the recommended levels of at least 300 and 200 kg ha^{-1}, respectively, compared with reduced fertilizer application (Seed Co., 2010). In contrast, the low profits associated with legume crops across all three farmer types could be due to the low projected grain and biomass yields. Low legume yields may be associated with the outlook of many farmers who view them as minor crops which can be planted late, require no mineral fertilizer, can be grown from retained seed and are planted in marginal fields (Giller *et al.*, 2011).

The projected level of profitability from the application of improved crop and livestock management practices increased

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across all three farmer types (Table 4). As was similar for the baseline scenarios, livestock enterprises generated the highest profits while legumes made a greater contribution to household income compared with cereals. This can be attributed to the high legume prices on the market. Crop–livestock integration can also be driven by population growth, policy developments and market forces (Wolmer, 1997). High producer prices for legumes relative to cereals increase the farmer's opportunity for profitably producing food and forage legumes which ultimately improves the scope for crop–livestock integration on smallholder farms.

Resultant crop–livestock integration

All farmer types experienced an increase in crop–livestock integration of 190, 60 and 150% for the OR, PT and YRE farmers, respectively, over the baseline. This can be attributed to improved crop and animal productivity across all farmer types. With regards to the individual components, all farm types had at least a 100% increase in the contribution of crops-to-livestock. This was mainly attributed to the increase in crop production where both grain and residue yields increased by at least 20% across all farmer types. The available land area and increased productivity of the different crops under the *OR* as opposed to the other farmer types led to the highest crop-to-livestock contribution of at least 190% in this category (Table 5).

Subsequently, *OR* farmers had the greatest increase in livestock-to-crops integration due to the hiring of extra labor to collect, carry and spread manure. The pattern was similar to the *YRE* farmers. For the latter farmer category, the increased integration was attributed to the increased manure use which was due to the increased awareness on the value of manure use in crop production. Farmers with more cattle will derive the most benefit from applying manure as a hectare of cropland ideally requires at least 30 t ha^{-1} of manure which requires at least 12 LU per year to produce (Chastain and Camberato, 2004). The actual amount of manure produced is dependent on the diet, method of feeding and collection. For example, while 1 LU of cattle produces at least 7000 kg yr^{-1} manure, the recovery rate of manure from animals that are kraaled overnight is only 30–40% or 2500 kg of manure (Nzuma, 2013). *PT* farmers who have <5.45 LU (Table 1) will thus produce about 6000 kg yr^{-1} of manure which may support less than 0.5 ha of cropland, resulting in lower productivity than the other two categories.

Conclusions

Current levels of crop–livestock integration are generally lower relative to the potential across smallholder farmer types in the Murehwa and Goromonzi districts of Zimbabwe. Specifically, individual and combined crop and livestock productivity is generally low across all the smallholder farmer types considered. Despite being low, crop–livestock integration is relatively higher for full-time farmers and lower for part-time farmers practicing mixed farming. Contribution of crops to livestock is greater as opposed to livestock contribution to crops, mainly due to the value of fodder and crop residues consumed by livestock being greater than the value of manure and draught power utilized in crop production. However, potential crop and livestock productivity and integration improvement strategies vary with farmer socio-economic status. Simulation modeling has indicated that improved crop agronomy and livestock husbandry can potentially increase both individual component and combined crop and livestock productivity for smallholder farming systems. System efficiency and profitability can potentially increase as a result. However, trade-offs in labor and soil fertility should be considered. Adoption of crop–livestock integration can potentially increase system value and income by at least 100% in specific smallholder systems, with access to land area and livestock holding influencing system outcomes. Integration is potentially improved in *OR* farmers through improved efficiency in crop and livestock productivity. This also includes increased labor availability, supplementary cattle feeding and use of cattle manure. PT farmers potentially improve integration through supplementary goat and cattle feeding and selling of small ruminants like goats. Among other options, inexperienced YRE farmers need improved access to crop and livestock extension to increase productivity and integration. While indications from the current study were based on modeled theoretical proposals for crop–livestock improvement and integration, there is a scope in assessing the practicability and feasibility of these results using on-farm trials in smallholder systems. The study therefore highlights that the first step toward improved crop–livestock integration in smallholder farming systems is increased component productivity through increased crop or livestock husbandry. Maximum use of by-products from either component in smallholder farms moves the systems toward an improved crop–livestock integrated state.

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