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Trade-offs and synergies associated with maize leaf stripping within crop-livestock systems in northern Ghana

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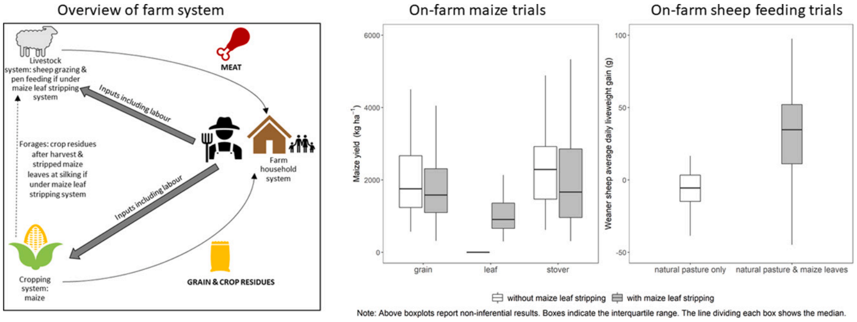
HIGHLIGHTS

- Forage accessibility and availability are a concern in crop-livestock systems; however, alleviating these concerns can generate trade-offs.
- We tested with farmers in Northern Ghana how maize leaf stripping in a maize monocrop affected maize and sheep productivity and labour requirements.
- Maize leaf stripping had no statistical effect on maize grain yield and had a statistically positive effect on average daily liveweight gain for sheep.
- Maize leaf stripping led to substantial changes in productivity and had knock-on effects within the farm system for labour and pen feeding.
- We show it is important to examine the effect of changes in crop management beyond the crop's field.

GRAPHICAL ABSTRACT



Note: Above boxplots report non-inferential results. Boxes indicate the interquartile range. The line dividing each box shows the median.

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ABSTRACT

CONTEXT: The accessibility and availability of forages is a common concern in crop-livestock systems in West Africa; however, options to increase forage production may entail trade-offs within the farm system that can be challenging to quantify explicitly.
OBJECTIVE: This study examined how maize (*Zea mays L.*) leaf stripping affected maize and sheep productivity and associated labour requirements, and farm system trade-offs and synergies in four communities in the Northern Region of Ghana.
METHODS: Maize leaf stripping involved removing almost senesced leaves from maize plants below the cob level at silking. We combined data from three sources: on-farm maize trials with 28 farmers from two seasons (2017 and 2018), on-farm sheep feeding trials where the pasture-based diets of weaner sheep were supplemented with

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stripped maize leaves fed in pens (conducted in 2019), and farm survey data from 117 households (conducted in 2014), seven of which were in the on-farm maize trials and owned sheep. We examined the trial data using linear mixed-effects models.

RESULTS AND CONCLUSIONS: Maize leaf stripping had no significant effect on maize grain yield but had a significant positive effect on maize forage protein yield from leaf and stover. Offering maize leaves to weaner sheep had a significant positive effect on average daily liveweight gain, estimated marginal mean was 29.3 g with maize leaves and −10.9 g without maize leaves. For the maize-sheep systems of the seven households, non-inferential statistics suggested that on average maize leaf stripping reduced total maize grain production by 12% (range −46 to 38) and increased maize forage protein production from leaf and stover by 90% (range −16 to 298). Stripping the maize leaves from one hectare of land took an extra 34 h (range 27 to 42) of labour, which was counterbalanced by reduced labour time for grazing as sheep were fed the maize leaves in pens. For the 117 farmers, heterogeneity in maize areas planted and livestock numbers resulted in heterogeneous production and labour effects of maize leaf stripping. Farmers qualitatively described how maize leaf stripping released labour so children could spend more time at school rather than shepherding.

SIGNIFICANCE: We quantified in northern Ghana how maize leaf stripping altered crop and livestock productivity and associated trade-offs and synergies in the farm system, including labour. Changes in crop management often have implications beyond the crop's field and examining these implications can provide insights into the suitability of alternative farm management options.

1. Introduction

Understanding the dynamics in farm systems that produce and alter the nature of trade-offs (defined as exchanges that occur as compromises) is central to achieving a sustainable and food-secure future (Klapwijk et al., 2014; Kanter et al., 2018). These trade-offs typically occur because a change in farm management influences what must be done in one cropping field or grazing area and may also involve compromises and situational decisions with other activities from which farmers generate their livelihood. These trade-offs become particularly acute if resources are constrained and if farmers have multiple goals (Patrick et al., 1983; Giller et al., 2008). Crop-livestock systems are one type of system where trade-offs and synergies are ubiquitous between systems, i.e., between crops and livestock (van Keulen and Schiere, 2004; Garrett et al., 2020). One management practice relevant to sustainable intensification within crop-livestock systems is maize (*Zea mays* L.) leaf stripping. Maize leaf stripping involves removing lower, almost senesced, leaves from the maize plant typically below the cob level around silking. Grain yields largely depend on the amount of assimilates that are captured and stored during the vegetative stage of crop growth as well as the onset of the senescence process itself (Thomas and Ougham, 2014; Schippers et al., 2015). One hypothesis is that maize leaf stripping increases maize grain yield when the removed leaves are becoming senescent and consequently have low photosynthetic capacity. These leaves, when they remain on the plant under low incident Photosynthetically Active Radiation, would conceivably become net importers of assimilates in competition with the developing cob. This hypothesis has been supported in Zimbabwe (Mashingaidze et al., 2012).

Maize leaf stripping involves at least three changes in farm system management at different hierarchical levels. First, maize leaf stripping can alter grain and stover (crop residue) yield. The yield effect of maize leaf stripping is dependent on many factors, such as the growth stage of maize and the physiologically-active leaves that remain after the almost senesced leaves are stripped. These factors affect the availability of assimilate to the active leaves through a reduced sink demand. This consequently increases the amount of available assimilate for the growth of the remaining plant parts, which in turn affects grain yield. Second, maize leaf stripping can increase the quantity of green forage available in the maize growing season, which can be a time of reduced forage accessibility due to farmers restricting livestock movement and access to grazing land in order to prevent damage to crops. This increase in green forage quantity may increase livestock production. Third, at the farm system scale, maize leaf stripping can change the demand for labour as maize leaf stripping requires time and feeding leaves is typically done in pens or through tethering and this may reduce time demands for supervised grazing but increase feed preparation time.

Concerns about the quality, accessibility, and availability of forages have implications for the goals of livestock farmers in West Africa, where livestock farmers typically aim to achieve an acceptable survival rate rather than maximum productivity (Sumberg, 2002). Maize leaf stripping has been described as most suitable when (a) farmers operate intensive mixed crop-livestock systems for the fattening of ruminants, (b) forage quality is poor, and (c) forage accessibility and availability is low (Lukuyu, 2015). Existing studies have reported a positive or neutral effect of maize leaf stripping on maize grain yields in both maize monocropping (Hoyt and Bradfield, 1962; Remison, 1978; Dzowela, 1987; Tanaka et al., 2010; Mashingaidze et al., 2012) and maize-legume intercropping (Subedi, 1996; Katsaruware and Manyanhaire, 2009; Raza et al., 2019). In the cropping system, the effect of maize leaf stripping extends beyond changing maize grain yields as it provides a forage resource through providing leaf and alters stover yields. Maize leaf stripping therefore affects forage availability and addresses forage accessibility concerns that then influence livestock productivity and labour requirements. Forage accessibility and availability are important in crop-livestock systems, where a limited supply of quality forages has consequences on the livelihoods of farmers in developing countries (Balehegn et al., 2020). Existing studies have analysed in crop-livestock systems the trade-offs associated with crop residue management (Klapwijk et al., 2014; Valbuena et al., 2015) and forage production (Tian et al., 2012; Komarek et al., 2015; Paul et al., 2020a; Paul et al., 2020b). Studies where livestock are an important part of the farm system may be more holistic if trade-offs are assessed (Salmon et al., 2018). Within farm systems, especially low-input systems in sub-Saharan Africa, labour requirements are a critical factor in assessing the fate of farm management options (Dahlin and Rusinamhodzi, 2019). In West Africa, a need exists to identify farm management options that are both yield enhancing and labour saving (Aune et al., 2017).

The objective of our study was to test how maize leaf stripping in a maize monocrop affects productivity, production, and labour requirements in the farm system (and its components of maize and sheep, i.e., a maize-sheep system) using data from the Northern Region of Ghana. Maize leaf stripping was examined using two treatments: (1) a control treatment of no leaves removed during the maize growing season, and (2) a maize leaf stripping treatment that involved removing all leaves at 50% silking that were below the cob level. Our study asked three questions: how does maize leaf stripping affect (1) maize yields of grain, leaf, and stover and total maize production over the maize growing season, (2) weaner sheep liveweight over a 72-day period, and (3) labour requirements for maize production? Recognizing that trade-offs in farm systems can be countless, we provide insights into how an option (maize leaf stripping) to increase forage availability affected the farm system, and the interactions among the maize and sheep components of the farm system. In our study, the word "forage" refers to the edible parts of plants (other than separated grain) that can provide feed for livestock.

2. Methods

2.1. Overview of methods and study communities

To quantify how maize leaf stripping affected maize-sheep systems in the Northern Region of Ghana we collected data from two types of on-farm trials: (1) maize trials that measured maize yields for grain, stover, and leaf biomass with and without maize leaf stripping, and (2) sheep feeding trials that measured the growth performance of weaner West African Dwarf sheep (Djallonke) with an average initial liveweight of 15.11 kg. These sheep are mainly raised for meat production. The sheep were either kept on a control diet of natural pasture only or on a diet of maize leaves and natural pasture. We also collected farm household survey data to provide the structural features of crop-livestock farm households, including households that grew maize and owned sheep and participated in the on-farm maize trials. The on-farm trials and surveys were conducted as part of the Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) Program.

The on-farm maize trials, on-farm sheep feeding trials, and household surveys were conducted in four communities in the Northern Region of Ghana (Table 1). These communities are located in the Guinea Savannah agro-ecological zone with unimodal rainfall, an annual precipitation of 800–1200 mm (FAO, 2005), and a tropical savannah Köppen-Geiger climate with a dry winter (Peel et al., 2007). The most common soils in the communities are either Gleysols, Lixisols, or Luvisols (Table 1). In the Northern Region, soils contain iron pan boulders, low to moderate amounts of total nitrogen, and low amounts of organic matter (Tetteh et al., 2016). Farm systems in the four communities are typically rainfed mixed crop-livestock systems. In our study, the "farm system" transforms land, capital, and labour into products that can be consumed or sold, and this system comprises the farm household, cropping system(s), and livestock system(s) (Fresco and Westphal, 1988). Maize and small ruminants (sheep and goats) are a major source of livelihoods in the four communities and across the Northern Region (Zaibet et al., 2011; Amankwah et al., 2012; Kuivanen et al., 2016; Michalscheck et al., 2018; Mellon-Bedi et al., 2020). Maize is typically planted, commonly as a monocrop, in July or August and harvested in November. Vegetables are grown throughout the year with off-season irrigation.

Table 1
Contextual details of each community in the on-farm trials.

District	Community	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (meters above sea level)	Reference soil group
Savelugu	Duko	9.561	−0.826	156 m	Gleysols and Luvisols
Savelugu	Tibali	9.669	−0.852	143 m	Luvisols and Gleysols
Tolon	Cheyohi No. 2	9.447	−0.988	146 m	Gleysols and Luvisols
Tolon	Tingoli	9.355	−1.006	143 m	Gleysols and Lixisols

Notes: Two most common Reference Soil Groups listed based on the World Reference Base for Soil Resources (IUSS, 2006) using each community's latitude and longitude in SoilGrids (Hengl et al., 2017).

Forage accessibility and availability concerns are common constraints for small ruminant production, and these constraints are typically seasonal. In the wet season from May to October, the main cropping season, compound and homestead farming that includes the tethering of livestock, can limit forage accessibility as farmers aim to restrict livestock movement to prevent damage to cultivated crops (Duku et al., 2010; Konlan et al., 2016; Konlan et al., 2018). Therefore, forage produced during the wet season, when maize is grown, could be an important source of livestock nutrition during this time of forage accessibility concerns. In the dry season from November to April a concern is declining forage availability, particularly natural pastures (Konlan et al., 2018), which are highly lignified and dried and eventually are burnt off by wild bushfires. Other constraints for small ruminant production include water shortages during the dry season and a lack of veterinary services to control diseases (Amankwah et al., 2012). Supplementary Information Section 2 provides additional details on the sheep system, including management and marketing. The graphical abstract includes an overview of the farm system studied.

2.2. On-farm trials experimental design

2.2.1. Maize trials

On-farm maize trials were conducted in the 2017 and 2018 maize growing seasons in the Northern Region of Ghana. A key objective of the on-farm maize trials was to measure grain, leaf, and stover yields in a maize monocrop with and without maize leaf stripping. In our study, the term "maize leaf" refers to the (almost fully) senesced leaf that is removed (stripped) from the maize plant below the cob at silking during the maize growing season. Silking is the start of the reproductive stage of maize growth. The experimental design for the on-farm maize trials was a Randomized Complete Block Design replicated with 28 farmers that were spread across the four study communities. There were 9 farmers in Duko, 6 farmers in Tibali, 6 farmers in Cheyohi No. 2, and 7 farmers in Tingoli. Farmers preferred to strip at silking and not at tasselling (Hoeschle-Zeledon, 2019). This preference was attributed to the self-reported ease of farmers to identify almost senesced leaves below the maize cob level at silking with a substantial biomass build-up of almost senesced leaves. At silking, maize silk can be easily seen at the tip of a growing ear; hence, farmers can easily see when it emerges from the ear. In addition, the farmers were trained on how to determine when the maize field reached 50% silking and where to strip the maize leaves from. The maize leaf stripping was done by the farmers under the supervision of field technicians. The on-farm maize trials had two treatments for a maize monocrop:

1. a "control treatment" with no maize leaf stripping.
2. a maize leaf "stripping treatment". The stripping of maize leaves was done once 50% of plants reached silking. The stripping involved the removal (stripping) of all almost senesced leaves below the cob level to ground surface. At 50% silking, most leaves under the cob will have senesced and are marginally photosynthetically active.

In the on-farm maize trials, farmers planted one of three open pollinated maize varieties of different maturity lengths: (1) Abontem (extra-early), (2) Omankwa (early), and (3) Obatanpa (medium). Days to maturity were 80 days for Abontem, 90 days for Omankwa, and 105 days for Obatanpa (Adu et al., 2014). The specific maize variety planted by each farmer was related to the time when the farmer's field was ready. Therefore, as each variety has a different maturity length, farmers who were ready to plant earlier were provided Obatanpa followed by Omankwa and then Abontem. This was done to avoid planting the Obatanpa variety (a longer duration variety) during the latter part of the maize growing season, which might have resulted in higher yield loss and may have discouraged farmers from participating in the on-farm maize trials. Each farmer planted the same variety in each season-treatment, 7 planted Abontem, 12 planted Obatanpa, and 9 planted Omankwa (Table SI.1 reports the distribution by community). All varieties were Quality Protein Maize varieties (Adu et al., 2014), i.e., they were bio-fortified with protein.

The on-farm maize trials were conducted in a field of each of the 28 farmers with the land area of each field being 4000 m^2. Each treatment was an even-sized plot within the field. Land preparation involved the use of tractor tillage and the planting of maize seeds was done manually with a garden line and dibblers. Stover was retained in each plot, but livestock could graze the stover. Maize was planted with a 75 cm spacing between rows and 40 cm in-row spacing. Three seeds were sown per hill and later thinned to 2 plants per stand at 14 days after sowing to attain a target maize population of 66,667 plants ha^{-1}. A uniform rate of mineral fertilizer was applied to all treatment plots at 5–8 cm from the plants for all farmers. This included a compound fertilizer of N-P_2O_5-K_2O-MgO-S-Zn (23–10–10-2-3-0.3%) applied at 29–13–13-2-4-4 × 10^{-2} kg ha^{-1} among all maize plants at 10–14 days after sowing. A top dressing of Sulphate of Ammonia was applied at 21 kg ha^{-1} N evenly among maize plants at 4–5 weeks after sowing. Plots were hand weeded at 3 weeks and 5 weeks after sowing or weeded when necessary. Maize was planted from 20 June to 7 August in the 2017 maize growing season and from 20 June to 19 July in the 2018 maize growing season (Table SI.2 reports the reports the distribution by community).

All yield data are reported as dry matter. The grain, stover, and leaf yield was measured from the two middle rows of each treatment plot in each maize growing season. The leaves below the cob level of maize plants in the harvest area of the stripping treatment plot were harvested to the ground level, oven dried at 65 °C to a constant weight and measured as leaf yield. The cobs from the plants in the two middle rows of each treatment plot were harvested, dehusked, shelled and oven dried at 65 °C to moisture content of 13% and measured as grain yield. After harvesting the cobs, the remaining plants (stalks and leaves) in the harvest area of each treatment plot were cut to ground level, oven dried at 65 °C to constant weight and measured as stover yield. Stover was measured as the weight of stalks and leaves at grain harvest.

Labour data for the time taken to strip maize leaves was collected from technology parks in 2018 (Hoeschle-Zeledon, 2019) from northern Ghana. The labour data included the time taken to strip green maize leaves at silking over a land area of 22.5 m^2 from three separate farmers (two male and one female). The recording of time started when the farmer was in the plot and ended when the maize leaves were stripped (i.e., harvested off the plant). Technology parks are community-based experimental stations consisting of a series of experiments (Supplementary Information Section 1).

2.2.2. *Sheep feeding trials*

On-farm sheep feeding trials were conducted from 25 September 2019 to 10 December 2019 to measure the effect of feeding stripped maize leaves on the growth performance of West African Dwarf weaner sheep. The on-farm sheep feeding trials were an experiment and contained two treatments:

1. A "control treatment" where weaner sheep grazed natural pasture each day from 8:00 AM until 5:00 PM. These sheep grazed on natural pasture as the sole source of nutrition and were not offered stripped maize leaves.
2. A maize leaf "stripping treatment" where weaner sheep were kept in a pen from 8:00 AM until 1:00 PM and offered stripped maize leaves. These maize leaves were generally provided in plastic troughs. The quantity of maize leaves offered in dry matter each day was ~2.5% of the sheep's liveweight. At 1:00 PM the sheep were released from the pen and joined the sheep in the control treatment to graze natural pasture until 5:00 PM.

In both treatments shepherd boys supervised the grazing of sheep on natural pastures along the main roads in the communities and other land that was not under crop cultivation.

A total of 80 Djallonke sheep (8–12 months of age) were provided by farmers in the four communities. In total, 16 farmers provided five sheep each. These 16 farmers were a subset of the farmers who participated in the on-farm maize trials. Four farmers in each community participated in the experiment. The experiment was replicated twice in each community, therefore as the experiment had two treatments each individual farmer only conducted one of the two treatments. Sheep were selected and identified with coloured nylon ropes around their necks. Farmer pens (~5 m × 8 m) that were damaged were repaired, pens were cleaned, and rice chaffs were use as litter. Ivermectin and oxytetracycline was administered as a prophylactic treatment prior to commencement of the on-farm sheep feeding trials. The sheep were weighed consecutively for two days at the beginning and end of the on-farm sheep feeding trials. The averages of these weights were used as the initial and final liveweights, respectively. Thereafter, the sheep were weighed every 14 days until the end of the 72-day on-farm sheep feeding trials.

Measurements were taken to determine (1) pasture species at the grazing locations (2) the nutrient composition of the natural pasture and maize leaves including their crude protein, neutral detergent fibre, ash, and acid detergent fibre, and (3) the in vitro organic matter digestibility of the sheep diets in both treatments. Supplementary Information Section 2 provides details on the methods used for the above three measurements. In the stripping treatment, measured quantities of the stripped leaves were offered, and the leftovers were weighed every morning and sampled every 14 days until the end of the on-farm sheep feeding trials. Collected forage and leftover samples were used for the determination of dry matter intake.

2.3. *On-farm trials statistical analyses*

We analysed the data from the maize trials and sheep feeding trials using linear mixed-effects models. We preformed the statistical analyses using the 'lmer' function in the 'lme4' package (Bates et al., 2015) in R version 4.0.2 (R Core Team, 2020). We used Restricted Maximum Likelihood to estimate the models. Parametric bootstrapping procedures with the 'bootMer' function were used to generate 95% confidence intervals for estimated coefficients using 599 iterations (Wilcox, 2010). Estimated coefficients were considered significant if the 95% confidence intervals did not overlap with zero and if the P value was <0.05 using the Kenward-Roger approximation of the degrees of freedom (Kenward and Roger, 1997). For model assumptions, we inspected the normality of residuals with quantile-quantile plots and inspected residual versus predicted values for the homogeneity assumption (Zuur et al., 2009). We used the 'emmeans' package to report the estimated marginal means for each treatment. For variance explained, Nakagawa et al. (2017) conditional R^2 and marginal R^2 were used.

2.3.1. *Maize trials*

Eq. (1) lists the model structure that was used to estimate how maize leaf stripping affected maize yield. Our observational unit was a plot.

$$Ln(yld) = tmnt + mzVar + (1 \mid \text{community}/farmer) + (1 \mid season) \tag{1}$$

In Eq. (1), yld = the dependent variable of annual maize yield and is a numerical variable (Ln = natural logarithm), $tmnt$ = fixed effect for treatment and is a nominal categorical variable with two classes (control and stripping), $mzVar$ = fixed effect for maize variety planted (nominal categorical variable), $community$ = name of community (nominal categorical variable), $farmer$ = farmer identification number (nominal categorical variable), and $season$ = season the maize crop was grown (2017 maize growing season or 2018 maize growing season). We specified a random effect for each community and the effect of farmer was nested in community. We also included a random effect for maize growing season. We transformed the yield variable in Eq. (1), which had a positive skewness (Fig. SI.1), using a natural logarithm to avert issues of non-symmetric distributions of variables (Tabachnick and Fidell, 2007). Estimated marginal means for the coefficients for the treatment variable were back transformed from the natural logarithm scale they were estimate in into their measurement units (kilograms). This back-transformation was done using the 'emmeans' package. Results for comparisons of the estimated marginal means between treatments are given on the natural logarithm scale and these results are averaged over the levels of variety.

We estimated three models separately and each model had a different dependent variable: (1) grain yield in kg ha^{-1}, (2) stover yield in kg ha^{-1}, and (3) forage protein yield defined as the sum of stover yield and leaf yield in kg crude protein ha^{-1}. The protein content of maize leaf was taken from the measurements conducted in Section 2.2.2. The crude protein content of maize stover was set at 39 g kg^{-1} (i.e., dry matter maize stover was 3.9% crude protein) (INRA et al., 2020). The descriptive statistics and the statistical analysis contained 112 observations: 28 farmers (each farmer was a replicate) with two plots each (one per treatment) in two maize growing seasons.

2.3.2. *Sheep feeding trials*

Eq. (2) lists the model structure that was used to estimate how maize leaf stripping affected average daily liveweight gain. Our observational unit was an individual sheep in a pen. The pen was the experimental unit.

$$ADG = tmnt + ILW + (1 \mid community) \tag{2}$$

In Eq. (2), ADG = the dependent variable of average daily liveweight gain (g day^{-1}) and was calculated as final weight (g) minus initial weight (g) divided by 72 and is a continuous numerical variable, $tmnt$ = fixed effect for treatment and is a nominal categorical variable with two classes (control and stripping), ILW = initial weight (kg) and is an independent continuous variable used as a covariate in the model, $community$ = name of community (nominal categorical variable). We specified a random effect for each community. Each community was considered as a random factor (block) in the statistical analysis. Because initial liveweights varied among the sheep, we tested for the significance of an interaction term between the explanatory variables using ANOVA: (1) $tmnt + ILW$, and (2) $tmnt \times ILW$. The on-farm sheep feeding trials were designed to have 80 weaner sheep (80 observations) in total: four communities with two replicates per community.

2.4. *Farm household survey data*

Farm household survey data was obtained from the Ghana Africa RISING Evaluation Survey (IFPRI, 2015; Tinonin et al., 2016). Survey interviews were conducted between May and July 2014 that covered the main cropping season of 2013. In total 117 farm households were interviewed in the four communities. From these 117 households, seven were involved in the on-farm maize trials for both seasons and reported owning sheep in the survey. The difference in sample size of 117 versus seven was because most of the 28 farmers in the on-farm maize trials joined the Africa RISING program after the household survey was conducted and two households did not own sheep. From the seven households, one was in Cheyohi No. 2, one was in Tingoli, two were in Duko, and two were in Tibali. From the 117 households, 31 were in Cheyohi No. 2, 22 were in Tingoli, 34 were in Duko, and 30 were in Tibali. These farm household data were used in the household maize-sheep system analysis (Section 2.5).

2.5. *Household maize-sheep system*

We calculated indicators for production and labour within the maize-sheep system for two groups of households by combining the data from the on-farm trials with the household survey data:

1. The seven sheep-owning households that were in the household survey and on-farm maize trials. We used individual household structural features, individual maize yields from the on-farm maize trials and estimated marginal means from the on-farm sheep feeding trials.
2. We also explored the effect of maize leaf stripping on maize-sheep system indicators for the 117 households based on the structural features of each individual household and estimated marginal means in the on-farm trials for maize and sheep feeding.

The estimated marginal means were taken from the statistical analysis using the full sample of on-farm trial data for maize and sheep feeding. The households we calculated indicators for were not representative (statistically or otherwise) of any underlying population and were not used for any statistical inference at the farm system scale. We calculated for each household using the household survey data: (1) area of maize planted (ha), (2) maize labour requirement (hours ha^{-1}) excluding maize leaf stripping time, (3) number of weaner sheep, and (4) number of weaner sheep equivalents. The question about livestock numbers in the household survey was for the total number of livestock owned per species across all classes of animal within the species. There was no breakdown of sheep numbers by class, for example no data on the number of weaners or number of ewes. To calculate total weaners, we assumed that 50% of the total sheep numbers were weaners. To calculate weaner sheep equivalents we converted all reported sheep, goats, and cattle into sheep equivalents using Tropical Livestock Unit conversion factors of 0.1 for sheep, 0.1 for goats, and 0.7 for cattle (Jahnke, 1982).

For the seven households we calculated the following indicators with and without maize leaf stripping on all maize land in the maize-sheep system:

- Total annual maize grain, leaf, and stover production based on the annual yields (kg ha^{-1}) recorded in the on-farm maize trials and the area of maize planted (ha) by the household from the household survey. Yields were from individual farmers in the 2017 and 2018 maize growing seasons. Maize area planted was from the household survey.
- Total annual forage protein production from maize leaf and stover available as a livestock forage, based on maize leaf and stover yields (kg ha^{-1}) and their crude protein contents (g kg^{-1} dry matter) from Section 2.3, and the area of maize planted (ha). Yields were from individual farmers. Maize area planted was from the household survey.
- Total liveweight gain for weaner sheep over the 72-day on-farm sheep feeding trial, based on the estimated marginal means in the trial, number of days in the trial, and the total number of weaners owned by each household from the 2014 household survey. The same estimated average daily liveweight gain was applied to all seven households. Weaner numbers were specific to individual farmers.
- Total labour demand per maize growing season for maize production, based on household survey data for the area of maize planted and maize labour requirements, and data on maize leaf stripping time from the technology park. Supplementary Information Section 3 describes how labour data was reported in the survey.

For the 117 households we calculated the following indicators with and without maize leaf stripping on all maize land in the maize-sheep system:

1. Total maize grain production based on individual household area of maize and the estimated marginal means from the on-farm maize trials.

2. Total weaner sheep liveweight gain based on individual household total weaner sheep equivalents and the estimated marginal means from the on-farm sheep feeding trials.
3. Total labour requirement for maize, computed using the same methods as for the seven households.

Although our quantitative data were for crop yields and liveweights from the on-farm trials and from the household survey, we also describe qualitative data that was gleaned during visits to the farmers involved in the current study.

3. Results

3.1. Results from on-farm maize trials

Across both seasons, summary (non-inferential) statistics suggested that maize leaf stripping reduced average maize grain yields by 3% and average maize stover yields by 15% (Table 2). Across both maize growing seasons, leaf stripping provided an average 1040 kg ha^{-1} (range 303–2137) of forage as maize leaves (Table 2). Total forage protein yield (sum of leaves stripped and stover) was greater if leaves were stripped. Substantial variation in yield levels and treatment effects existed for individual farmer-season combinations (Fig. 1 and Fig. SI.2). The grain yield effect of maize leaf stripping was negative for 35 out of 56 farmer-season combinations (56 = 28 farmers × 2 seasons). The stover yield effect of maize leaf stripping was negative for 45 out of 56 farmer-season combinations. Maize leaf stripping increased forage protein yield for 54 out of 56 farmer-season combinations (Fig. 1). Maize grain yields were lower in 2018 than in 2017 (Table 2), possibly due to the distribution of precipitation during the maize growing season (Fig. SI.3) and its potential consequences on nitrate leaching (Supplementary Information Section 4).

Statistical analysis suggested that maize leaf stripping had no significant effect on grain yield, had a significant negative effect on stover, and had a significant positive effect on forage protein yield (Table 3). The estimated marginal mean for grain yield in the control treatment was 1826 kg ha^{-1} and in the stripping treatment maize yield was 176 kg ha^{-1} less at 1650 kg ha^{-1} ($P = .195$). Maize leaf stripping reduced maize stover yield by 530 kg ha^{-1} with the estimated marginal mean in the control treatment of 2471 kg ha^{-1} versus 1941 kg ha^{-1} in the stripping treatment ($P < .01$). Maize leaf stripping increased forage protein yield from leaf and stover by 81.7 kg ha^{-1} with an estimated marginal mean in the control treatment of 96.9 kg ha^{-1} versus 178.6 kg ha^{-1} in the stripping treatment ($P < .01$).

Table 2
Summary (non-inferential) descriptive statistics of maize yields from 28 on-farm maize trials.

Season	Item	Units per ha	Maize leaf stripping treatment average (CV)		Percent difference
			Control	Stripping	
2017	Grain	Kg	3060 (0.49)	2909 (0.55)	−2
2018	Grain	Kg	1368 (0.43)	1225 (0.48)	−5
2017	Stover	Kg	4525 (0.73)	4113 (0.73)	−4
2018	Stover	Kg	1896 (0.42)	1453 (0.60)	−26
2017	Leaf	Kg		1039 (0.47)	
2018	Leaf	Kg		1040 (0.51)	
2017	Stover and leaf	Kg crude protein	176 (0.73)	260 (0.61)	70
2018	Stover and leaf	Kg crude protein	74 (0.42)	157 (0.42)	132

Notes: Sample size is 112 plots. All kilograms, kg, are in dry matter. Season is maize growing season. For strip leaves columns, control treatment is no maize leaf stripping, stripping treatment is stripped all maize leaves below the cob level when 50% of plants reached silking. CV is coefficient of variation, standard deviation divided by average. Percent difference is average of plot difference. *Source*: authors' calculations and Hoeschle-Zeledon (2019) reports summary data of the grain and leaf yields from these on-farm trials for the 2018 season, aggregated across all communities. Table SI.3 reports economic yields.

The proportion of variance explained by the fixed effects (marginal R^2) and random effects (conditional R^2 − marginal R^2) was 0.016 and 0.694 for grain, 0.043 and 0.755 for stover, 0.175 and 0.53 for forage protein yield. Supplementary Information Section 4 provide details on the season random effects. We had no a priori reason to suspect an interaction between treatment and season.

3.2. Results from on-farm sheep feeding trials

Summary (non-inferential) descriptive statistics suggested that sheep in the control treatment lost liveweight with an average daily liveweight loss of 11.4 g and that sheep in the stripping treatment gained liveweight with an average daily liveweight gain of 29.6 g (Table 4). These averages mask substantial variation between sheep (Fig. 2 and Fig. SI.6). Given the initial liveweights, each sheep was offered on average 375 g of maize leaves each day, with an average 121 g being consumed per sheep (Table 4).

From the statistical model, average daily liveweight gain was on average an estimated 40.30 g more in the stripping treatment than in the control treatment (estimated coefficient = 40.30, standard error = 4.09, 95% confidence interval [32.10, 48.40]). The estimated marginal mean for average daily liveweight gain was −10.9 g for the control treatment (standard error = 3.56, 95% confidence interval [−19.5, −2.37]) and was 29.3 g for the stripping treatment (standard error = 3.53, 95% confidence interval [20.8, 37.86]). In estimating these marginal means the covariate initial liveweight (*ILW* in Eq. (2)) was set to its average value. The proportion of variance explained by the fixed effects was 0.718 and by the random effects was 0.014. A likelihood ratio test indicated that the model with no interaction term ($tmnt + ILW$) was not significantly different from the model with an interaction term ($tmnt \times ILW$) ($\chi^2 = 2.30$, $P = .12$). We therefore retained the model that had no interaction (Eq. (2)). Figs. SI.7–SI.8 are plots for normality of residuals and homogeneity.

Compared to maize leaves, the natural pasture had less crude protein content and higher neutral detergent fibre, ash, and acid detergent fibre (Table SI.4), with the density of natural pastures in plants per m^2 reported in Supplementary Information Section 5. These differences in nutritive value (Table SI.4) resulted in sheep in the stripping treatment (offered maize leaves and natural pasture) having a more digestible diet than sheep in the control treatment (offered natural pasture only). The in vitro organic matter digestibility (48 h; % dry matter) was 44.4% in the control treatment and 48.1% in the stripping treatment.

3.3. Household maize-sheep system (non-inferential) results

Heterogeneity existed in household family size, maize area and labour requirements, and livestock numbers (Table 5). Here we focus on the descriptive summary of the seven sheep-owning households also in the on-farm maize trials. Households had a median 9 family members with 5 members aged 15 to 64 years old and 4 members aged less than 15 years old. They cultivated on average 1.6 ha of maize (range 0.6–4). Households reported requiring 589 h ha^{-1} for maize production. Because no farmers reported stripping maize leaves in the survey, the 589 h excluded labour time for maize leaf stripping (Table 5). Harvesting, planting, and weeding consumed the most labour time. The time to strip one hectare of maize leaves was 33.66 h (range 26.79–42.22) and the time to strip 1000 kg was 33.73 h (range 29.05–38.15). Therefore, maize production with maize leaf stripping used 5.6% more labour hours per hectare than maize production without maize leaf

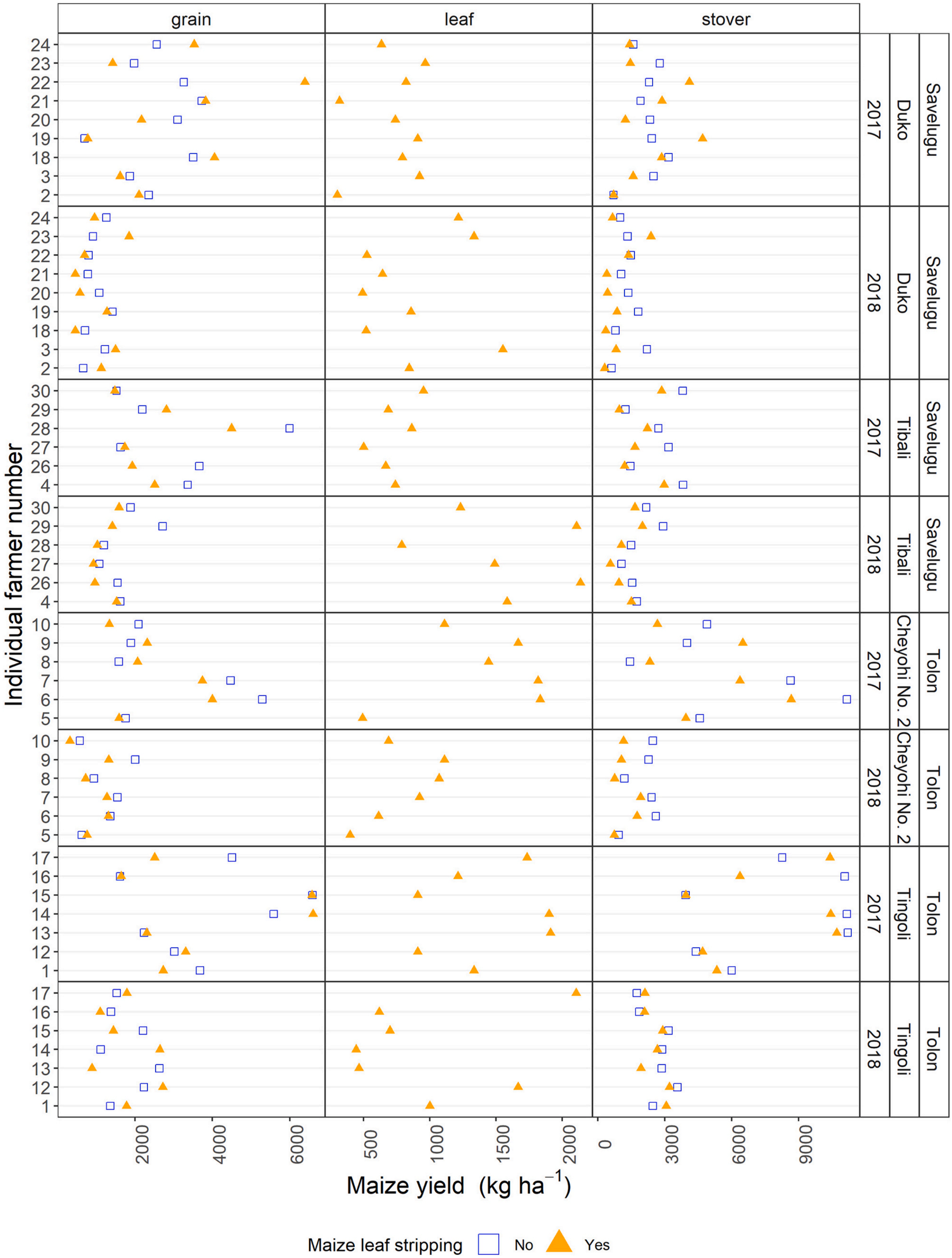

Fig. 1. Individual farmer maize yield of grain, leaf, and stover in each treatment by maize growing season, community, and district. “No” maize leaf stripping is the control treatment, and “Yes” maize leaf stripping is the stripping treatment. Maize leaf stripping involved the stripping of all leaves below the cob level when 50% of plants reached silking. *Source*: authors’ calculations and Hoeschle-Zeledon (2019) reports summary data of the grain and leaf yields from these on-farm trials for the 2018 season, aggregated across all communities.

Table 3
Linear mixed-effects model results for predicted per hectare maize yields.

Term	Grain			Stover			Forage crude protein (leaf + stover)		
	Coefficient	95% confidence interval	*P* value	Coefficient	95% confidence interval	*P* value	Coefficient	95% confidence interval	*P* value
(Intercept)	7.61	6.79–8.58	0.02**	8.00	7.06–9.01	0.01***	4.69	4.06–5.30	0.02**
Tmnt: stripping	−0.10	−0.25–0.06	0.19	−0.24	−0.39–0.09	<0.001***	0.61	0.45–0.74	<0.001***
Variety: abontem	−0.19	−0.48–0.10	0.22	−0.32	−0.68–0.00	0.07*	−0.22	−0.48–0.05	0.14
Variety: omankwa	−0.12	−0.39–0.17	0.39	−0.26	−0.57–0.05	0.12	−0.14	−0.41–0.12	0.30
Random effects									
σ^2 (within-subject variance)	0.17			0.17			0.17		
τ_{00} (between-subject variance)	0.05 $_{\text{farmer:community}}$ 0.03 $_{\text{community}}$ 0.33 $_{\text{season}}$			0.07 $_{\text{farmer:community}}$ 0.19 $_{\text{community}}$ 0.36 $_{\text{season}}$			0.04 $_{\text{farmer:community}}$ 0.12 $_{\text{community}}$ 0.16 $_{\text{season}}$		
ICC (intraclass-correlation coefficient)	0.71			0.79			0.64		
N (groups)	28 $_{\text{farmer}}$ 4 $_{\text{community}}$ 2 $_{\text{season}}$			28 $_{\text{farmer}}$ 4 $_{\text{community}}$ 2 $_{\text{season}}$			28 $_{\text{farmer}}$ 4 $_{\text{community}}$ 2 $_{\text{season}}$		
Observations	112			112			112		
Marginal R^2/Conditional R^2	0.016/0.710			0.043/0.798			0.175/0.704		

Notes: The reference level for the treatment factor (Tmnt) is no leaf stripping and the reference level for the maize variety (Variety) is Obatanpa. *$P < .1$; **$P < .05$; ***$P < .01$. Figs. SI.4–SI.5 are plots for normality of residuals and homogeneity. *Source*: authors' calculations.

Table 4
Summary (non-inferential) descriptive statistics for weaner sheep weight and diet over 72-day on-farm sheep feeding trials.

Item	Units	Control	Stripping
Average initial liveweight	Kilograms sheep^{-1}	15.18	15.04
Average final liveweight	Kilograms sheep^{-1}	14.35	17.17
Average liveweight gain	Kilograms sheep^{-1}	−0.82	2.13
Average daily liveweight gain	Grams sheep^{-1} day^{-1}	−11.4	29.6
In vitro organic matter digestibility	48 h; % dry matter	44.4	48.1
Average maize leaves offered	Grams sheep^{-1} day^{-1}		375
Average maize leaves leftover	Grams sheep^{-1} day^{-1}		253.7
Average maize leaf intake	Grams sheep^{-1} day^{-1}		121.3

Notes: Maize offered and maize leftover was measured in dry matter. Maize leaf intake equalled maize leaf offered minus maize leaf leftover. Control (column 3) stands for no maize leaf stripping and a diet of natural pasture only. Stripping (column 4) stands for maize leaf stripping and a diet of natural pasture and stripped maize leaves. *Source*: authors' calculations.

stripping. Households owned on average 7 sheep, 8 goats, and 3.6 cattle. For the seven households over the 12 months prior to the survey in 2014, grazing was the only reported source of feed for ruminants and no household reported feeding green forages to ruminants. From the entire sample of 117 households, grazing was the only reported source of feed for sheep and goats in 98 of the 115 households and for cattle in 17 out of 18 households, with feeding crop residues and green forages sparingly reported (Table SI.5). Labour data on livestock for the seven households suggested that ruminants were managed with supervised grazing for between 9 and 12 h every day of the year. Cattle numbers had a positive skew with a median of zero and one household owning 25 cattle. For the maize-sheep system, maize leaf stripping (compared to no maize leaf stripping) reduced average total grain production, reduced average total stover production, increased average total forage available, and increased average liveweight gains for weaner sheep. These differences in maize area and labour requirements and numbers of livestock influenced the effect of maize leaf stripping at the farm system scale (Table 6 and Fig. 3).

At the farm system scale, based on Table 5 and experiment-wide estimated marginal means, maize leaf stripping reduced total maize grain production, but generated extra forage (Table 6). On average, maize leaf stripping required 6% more labour time for maize field operations (Table 6). Variation among individual farmers in their maize area and labour required, and number of livestock owned existed (Table 5). The variation resulted in a range of effects of maize leaf stripping on total maize grain production, total maize labour required, and total change in liveweight gain (Fig. 3). Assuming all maize land was managed using maize leaf stripping, the median household had 214 kg less maize grain produced on their farm, but because of the variation in maize area planted the range was −1523 kg to −36 kg (Fig. 3). Total liveweight gain was more for skewed than grain production, with a median of 14 kg more liveweight gain under maize leaf stripping and a range of 1.5 kg to 389 kg. This range highlights the scope to tailor maize leaf stripping to farmer livestock numbers and individual circumstances (Section 4).

Four qualitative results also emerged from the analysis of the maize-sheep system. First, maize leaf stripping altered labour requirements. Practicing maize leaf stripping allowed the shepherd boy to attend school in the morning and then attend to the sheep in the afternoon after school while improving growth performance of sheep from the nutritive forage at a time of limited forage accessibility. Second, the confinement of sheep in the pens in the stripping treatment for part of the day provided the possibility for the more efficient collection of livestock manure (relative to the control treatment). Third, farmers believed that confinement of sheep in pens also had the benefit of reducing the exposure of sheep to pests and disease. Fourth, farmers felt that keeping sheep in pens may reduce the risks of livestock theft.

4. Discussion

Our study quantified the direct effect of maize leaf stripping on maize yields and sheep liveweights, changes in maize and sheep production quantities, and some of the labour requirements within maize-sheep systems in northern Ghana. We discuss three themes in this section. First, the reasons underlying why maize leaf stripping had a negative effect on grain yields and had a positive effect on forage protein yields and average daily liveweight gain for weaner sheep. Second, the implications of maize leaf stripping on farm system production and labour. Third, the importance of trade-offs and farmer heterogeneity in assessing the suitability of maize leaf stripping for farmers.

First, although the descriptive statistics showed average maize grain yields being lower if maize leaves were stripped, the effect of maize leaf stripping was not statistically significant. Maize leaves below the ear have been shown to make little contribution to grain dry matter

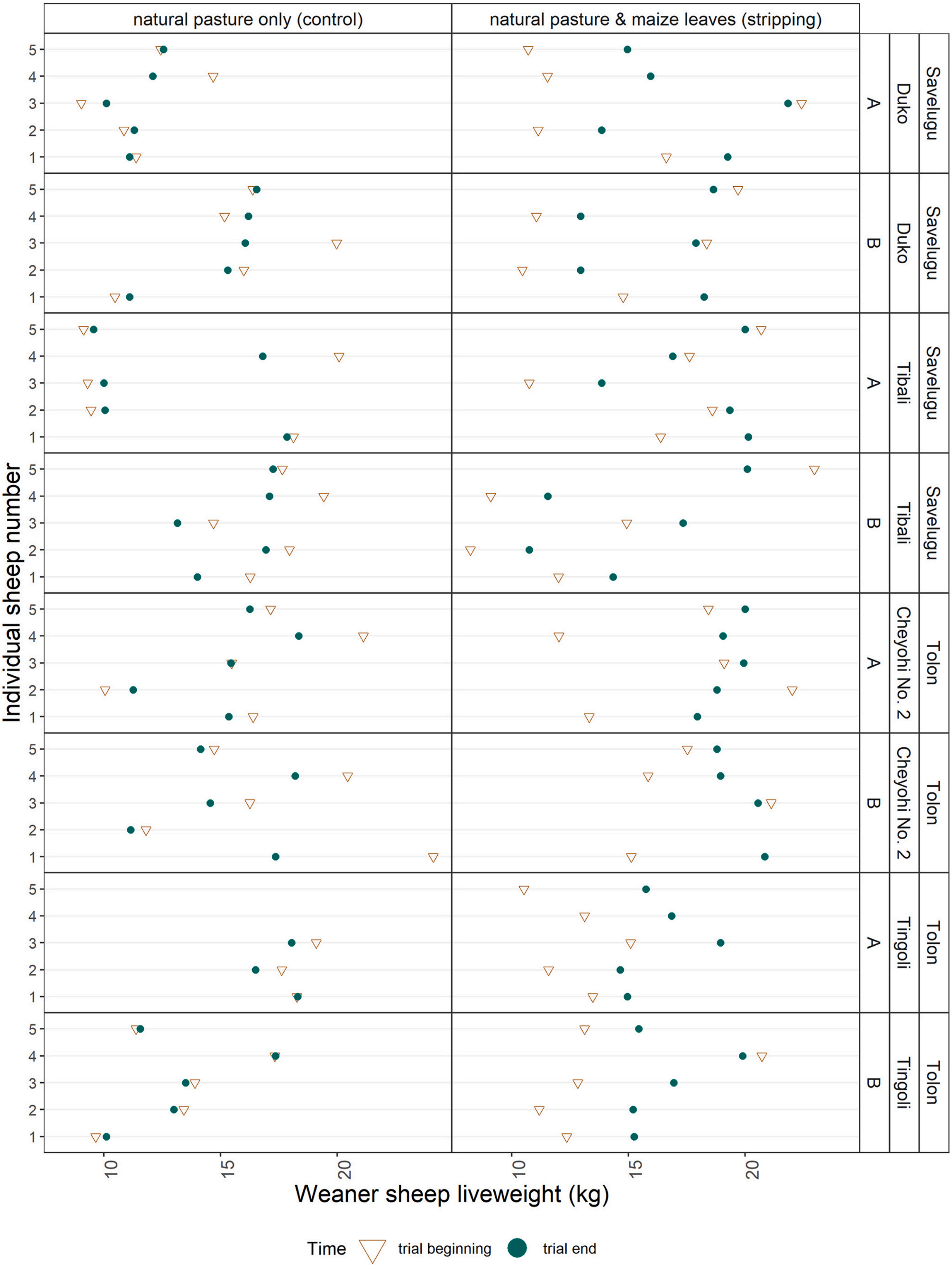

Fig. 2. Liveweight of individual sheep at beginning and end of on-farm sheep feeding trials in each treatment by replicate (A or B) and community and district. Duration of on-farm sheep feeding trials was 72 days. Individual sheep numbers are treatment and replicate specific. *Source*: authors' calculations.

Table 5

Summary (non-inferential) descriptive statistics of households.

Item	Units	Trial households (N = 7)	Full sample (N = 117)	Technology park (N = 3)
		Average (CV)	Average (CV)	Average (CV)
Total household members	Number	9.4 (0.16)	10.2 (0.45)	
Household members 15 to 64 years old	Number	5 (0.23)	4.9 (0.48)	
Maize area	Ha	1.6 (0.70)	1.5 (0.77)	
Total sheep	Number	7.1 (0.49)	6.1 (1.04)	
Total goats	Number	7.9 (0.79)	5.9 (0.78)	
Total cattle	Number	3.6 (2.65)	1.3 (3.75)	
Total maize labour requirement (excluding leaf stripping)	Hrs ha^{-1}	589 (0.46)	719 (0.55)	
Leaf stripping labour requirement	Hours 1000 kg^{-1}			33.74 (0.14)
Leaf stripping labour requirement	Hrs ha^{-1}			33.66 (0.23)

Notes: CV is coefficient of variation, standard deviation divided by average. N is number of observations. Trial households were a subset of the full sample that were in the on-farm maize trial and owned sheep. Kg in dry matter. Maize leaf stripping was the removal of all leaves below the cob level when 50% of plants reached silking. Total maize labour requirement included time allocated to, among others, land preparation of harrowing and ridging, planting, fertilization, weeding, harvesting, and other activities of spraying for pesticides, herbicides, and weedicides. *Source*: authors' calculations from data collected as part of the Ghana Africa RISING Evaluation Survey and from technology parks for maize leaf stripping labour.

Table 6

Summary (non-inferential) descriptive statistics of the maize-sheep system indicators with and without maize leaf stripping for seven sheep-owning households.

Item	Units	Maize leaf stripping treatment average (CV)		
		Control	Stripping	Percent difference
Grain yield	Kg ha^{-1}	2005.8 (0.50)	1764 (0.53)	−12
Stover yield	Kg ha^{-1}	3290.4 (0.90)	2265.4 (0.83)	−30
Leaf yield	Kg ha^{-1}		1010.9 (0.42)	
Total grain production	Kg season^{-1}	3282.3 (0.93)	2660.9 (0.78)	−12
Total stover production	Kg season^{-1}	4887.8 (0.92)	3171.8 (0.82)	−30
Total leaf production	Kg season^{-1}		1491.8 (0.56)	
Total forage protein production from maize leaf and stover	Kg season^{-1}	190.6 (0.92)	266.9 (0.48)	90
Total weaner sheep liveweight gain	Kg 72 days^{-1}	−2.8	7.5 (0.48)	
Total labour time for maize production	Hr season^{-1}	838.9 (0.70)	889.2 (0.68)	6

Notes: Yield data averaged over two seasons of on-farm maize trials. All kilograms (kg) are in dry matter. CV is coefficient of variation, standard deviation divided by average. For strip leaves columns, control treatment is no maize leaf stripping, stripping treatment is stripping all maize leaves below the cob level when 50% of plants reached silking. Duration of on-farm sheep feeding trials was 72 days. Hr = hours. Percent difference is average of difference for each household. *Source*: authors' calculations.

accumulation for maize (Hoyt and Bradfield, 1962; Tanaka and Yamaguchi, 1972; Remison, 1978). In Zimbabwe, leaf stripping at anthesis (50% silking) increased yields by 16.6–28%, whereas leaf stripping at three to four weeks before or after anthesis had no significant effect on yield (Mashingaidze et al., 2012). In Nepal, defoliation of maize by removal of leaves below and above the ear, or by topping 30 days after 50% silking, had no effect on maize grain yield (Subedi, 1996). However, despite these neutral to positive grain yield effects in previous studies, it is possible that maize leaf stripping may reduce maize grain yields.

One reason for the grain yield penalty (in the descriptive statistics) was that maize leaf stripping could have included the removal of physiologically-active leaves. These leaves may not have deteriorated enough, and this may have resulted in less photosynthesis and substrate transmission for grain filling, compared with the control treatment. Although not directly examined in our study, the role of chlorophyll sensors to identify the stage of leaf senescence may be worthwhile exploring as this could assist with decisions about what leaves to strip to reduce possible grain yield penalties. In the stripping treatment the removal of maize leaves at silking meant that stover yields at the end of the growing season were lower than in the treatment without maize leaf stripping. Forage protein yield (leaves stripped at silking plus stover at harvest) was greater in the stripping treatment as the cumulative benefit of stripped leaves towards forage protein yield exceeded the negative effect of reduced stover yields over the season. The leaves were stripped at a time when they were still undergoing some photosynthesis and farmers generally collected leaves that had lodged. At the time of maize leaf stripping, photosynthesis rates for the leaves had started to slow, but at least maximum leaf yield had been reached. The greater nutritive value of the stripped leaves led to increased sheep liveweight gains in the on-farm sheep feeding trials. The trade-off between forage production and grain production would be relevant for the management of crop-livestock systems.

Second, farm systems in West Africa face labour constraints and options for changes in farm management should be sensitivity to labour burdens in addition to changes in production (Aune et al., 2017; Dahlin and Rusinamhodzi, 2019). Maize leaf stripping increased labour requirements for maize production by 5.6% per hecatre. Although not directly examined in our study, a possible labour-saving approach to explore further includes using secateurs to remove the maize leaves rather than a knife. The labour time required for maize production (excluding maize leaf stripping) in our study was similar to existing studies in Ghana (Franke et al., 2010; Awunyo-Vitor et al., 2016; Kermah et al., 2017). However, maize leaf stripping has implications for the farm system beyond the cropping system. Feeding maize leaves to livestock produced a synergy as it reduced labour requirements for supervised grazing as sheep were pen fed the stripped maize leaves. Pen feeding the sheep in the morning required less labour time than supervising sheep grazing. Labour time is both related to harvesting the stripped leaves and processing the leaves so that they can be fed to sheep. Quantifying all the time required in each treatment is complex as pen feeding also needs intermittent supervision and time to prepare the leaves. Children who were part of managing sheep in the control treatment supervised sheep grazing in the morning, and children who were part of managing sheep in the stripping treatment provided the stripped maize leaves to sheep in a pen in the morning and then the children went to school. The design of the on-farm sheep feeding trials allowed children to attend school in the morning. Our calculation for change in sheep liveweight provides an indication of some of the benefits of maize leaf stripping but it may understate the full benefit of maize leaf stripping. This is because we only considered change in weaner sheep liveweights over the 72-day feeding trial.

Third, our data showed the heterogeneity among farmers in how maize leaf stripping affected their maize yields and sheep liveweights and subsequent production based on the heterogeneity among household maize area planted and number of sheep owned. Our data also

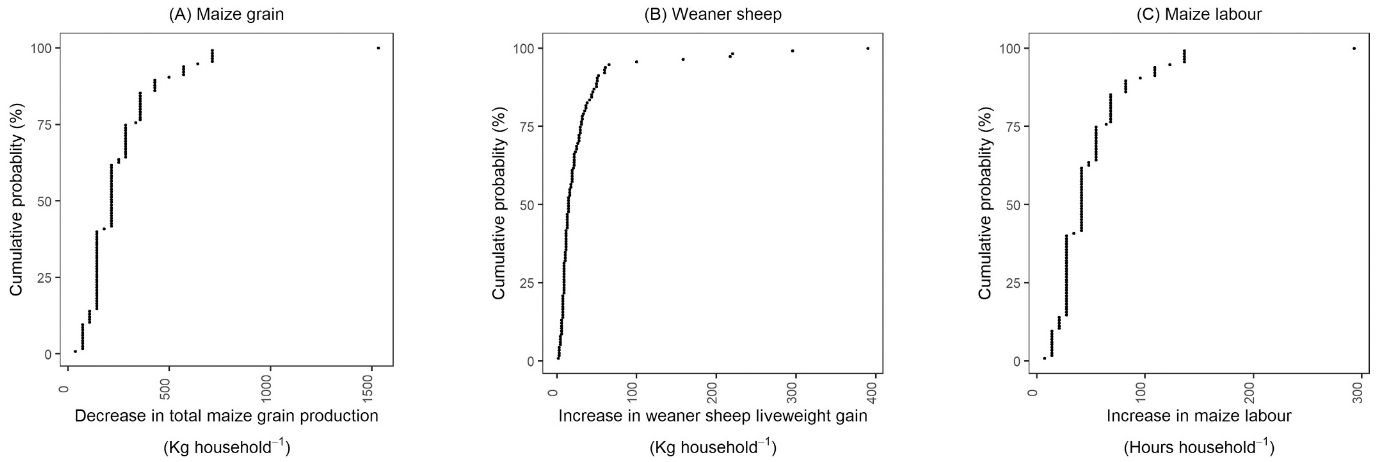

Fig. 3. Effect of maize leaf stripping on household (A) annual production of maize grain, (B) weaner sheep liveweight gain over 72 days, and (C) annual maize labour required using full sample of 117 households. Data based on individual household area of maize planted, sheep numbers (with goats and cattle converted into sheep using Tropical Livestock Units), and reported labour required per ha. Data for maize grain yields and weaner sheep liveweight gain based on estimated marginal means (Sections 3.1 and 3.2). Each marker is an individual farm household. *Source*: authors' calculations.

revealed a number of trade-offs and synergies including maize leaf stripping resulting in a (from the descriptive statistics) grain yield penalty but extra forage available and therefore more sheep liveweight, with an uncertain effect on total labour requirements. And although substantial heterogeneity existed in the yield effect of maize leaf stripping, maize leaf stripping typically improved total forage supply. Recommendations for changes in farm management based on averages can be misleading (Vanlauwe et al., 2019). We also show that recommendations for changes in farm management based on how it affects one component of the farm system may be misleading if the farm management practice has repercussions among other components of the farm system.

Related to heterogeneity is the adoption potential of maize leave stripping. An approach to consider adoption is through the diffusion of innovation theory (Rogers, 2003), where five perceived attributes of an innovation influence the innovation's adoption: relative advantage, compatibility, complexity, trialability, and observability. Our study focused on relative advantage considering changes in maize grain yield and liveweight gain, and labour requirements. We then examined the implications of these changes for seven sheep-owning households, the use of sheep provided consistency between the livestock species used in the on-farm feeding trials and the scaling of results for change in liveweight using the household data. Feeding maize leaves to only weaner sheep would most likely generate an excess of maize leaves if all maize land was stripped; however, farmers could also feed the maize leaves to their goats and cattle (Table 5). Maize leaf stripping has a divisibility dimension as the proportion of land stripped could be varied without likely large changes in costs or benefits per unit of land area. Maize leaf stripping also has a tactical dimension as it could be practiced on a season-by-season basis without substantial temporal productivity dependencies. These divisible and tactical dimensions increase compatibility and trialability attributes. For example, farmers could vary the area of maize leaves stripped based on the number of livestock owned, especially fattening livestock (Lukuyu, 2015), to better match maize leaf supply and demand at the farm system scale, also considering leaf storage potential (Supplementary Information Section 2). Overall, maize leaf stripping has several attributes making it an option to consider for farmers in the four communities, especially as maize leaf stripping has some relative advantages, is trialable, and can be observed through the technology parks. Compatibility within local crop-livestock systems could be tailored based on livestock numbers, especially fattening livestock, and the proportion of total maize area stripped to meet livestock feed demand. The quantity stripped would need to be compatible with leaf storage capacity and drying feasibility, especially during the wet season. The heterogeneity among household structural features and the productivity effects of the maize leaf stripping would mean any advice for farmers would require tailoring to their individual circumstances.

Maize leaf stripping also had four repercussions beyond the direct change in productivity. One of these repercussions was related to labour for grazing supervision and maize leaf stripping allowing the shepherd boy to attend school in the morning and possible implications for education. The net effect of maize leaf stripping on sheep labour requirements would also be related to several factors beyond grazing supervision. Some of these factors include time required to move leaves from the field to the feeding location, and time for pen feeding related to chopping, drying and storage, daily preparation of rations, and cleaning pens. Three other repercussions related to sheep in the stripping treatment being pen fed for part of the day. First, the confinement in pens could make manure collection more efficient (relative to the control treatment) as animals are in a more confined space. The absolute gains from more efficient manure collection would be related to total sheep numbers and how the sheep manure is recycled within the production system. With the benefits of more efficient manure collection contingent on its efficient handling, storage, and transport (Rufino et al., 2006). Farmers in different contexts have repeatedly mentioned that manure improves soil organic matter content (Adams, 2015; Castellanos-Navarrete et al., 2015). Although legume residues generally have higher nutritive value than maize residues (Palm et al., 2001), maize leaves stripped at silking can also be a high-protein source. Especially when the maize varieties planted, such as in our study, are Quality Protein Maize varieties. This suggests that the stripping treatment may possibly also produce higher quality manure. Second, the confinement in pens reduced the perceived risk of sheep being exposed to pests and diseases, as also noted in existing studies in the Northern Region (Adams, 2015). Third, the confinement in pens reduced the perceived risk of sheep theft. This is because the pens are typically located around the homestead and this is considered a safe place, also noted elsewhere (Adams, 2015). In Kenya, cattle farmers also prefer to keep cattle in stalls to avoid theft, especially at night (Castellanos-Navarrete et al., 2015). We were unable to directly quantify these repercussions and they were based primarily on qualitative data gleaned from visiting farmers involved in the current study. Nevertheless, these repercussions would influence the overall performance of the farm system.

5. Conclusion

We studied the effect of maize leaf stripping on productivity, production, and labour requirements within farm systems in the Northern Region of Ghana. Overall, our analysis showed that maize leaf stripping tended to have more positive interactions than negative interactions with the performance of the farm system. This was because maize leaf stripping had no statistical effect on maize grain yield and had a positive statistical effect on forage protein yield and sheep liveweight gain. Although maize leaf stripping increased labour requirements for maize production field activities, feeding sheep maize leaves in pens released labour time for children to attend school. Beyond how maize leaf stripping directly affected maize yield and sheep liveweights, it would be important to further quantify the co-benefits of maize leaf stripping that offer further dividends on farm system performance such as livestock forage needs over the lifetime a sheep flock. Although not quantified directly in our study, important qualitative observations were made, some included labour allocation and schooling for children, how increased time pen feeding may affect the susceptibility of livestock to pests and diseases, risk of theft, and the efficiency of manure collection. Overall, our analysis suggested that maize leaf stripping is a farm management option that could be further canvassed when examining sustainable intensification options in crop-livestock systems.

Data availability statement

The data and scripts for our study are here https://doi.org/10.7910/DVN/NMFEFS.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

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Appendix A. Supplementary Information

Supplementary information to this article can be found online at https://doi.org/10.1016/j.agsy.2021.103206. This includes Supplementary Information Section 1 to Supplementary Information Section 5, Fig. SI.1 to Fig. SI.8, and Table SI.1 to Table SI.5.

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