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The forgotten agriculture-nutrition link

Estimating the energy requirements of different farming technologies in rural Zambia with time-use data

Thomas Daum, Filippo Capezzone, and Regina Birner

Abstract

In the quest to reduce global under- and malnutrition, which is particularly high among smallholder farmers, agriculture-nutrition linkages have received a lot of attention in recent years. Researchers have analysed the link between the quantity of food that farmers produce and nutritional outcomes and the link between farm diversity and consumption diversity. A third agriculture-nutrition link has been largely neglected in recent years: the impact of how food is produced on human energy requirements, and, consequently, nutritional outcomes. This neglect persists despite the fact that the majority of smallholder farmers in Sub-Saharan Africa rely on hand tools for farming, which implies heavy physical work and, thus, high energy requirements. To address this research gap, the present study compares the energy requirements of farm households in rural Zambia that are characterized by three different levels of mechanization: hand tools, animal draught power and tractors. Detailed time-use as well as food and nutrition data was collected from male and female adults and from children during different seasons: land preparation, weeding and harvesting/processing. Subjects recorded time-use themselves using an innovative picture-based smartphone app called "Timetracker". The time-use data served to calculate daily energy requirements using "Ainsworth's Compendium of Physical Activities". To analyse the link between mechanization and energy use as well as nutritional outcomes, linear mixed models and multiple linear regressions were used. The results show that during land preparation, individuals in non-mechanized households are, on the average, not able to meet their dietary energy requirements. In subsequent farming periods, results are more mixed. Gender differences are noteworthy throughout, with men mostly having higher physical activity levels and energy requirements compared to women The findings suggest that farm technologies affect nutritional outcomes substantially and that this neglected agriculture-nutrition linkage deserves more scientific and political attention in order to reduce the prevalence of both under- and malnutrition among smallholder farmers, while safeguarding against emerging double burden of nutrition.

Keywords: Agricultural mechanization, agricultural transformation, nutrition sensitive agriculture, physical behaviour, caloric requirements, time-use, gender, time-use, Africa

JEL codes: I12, I15, I18, J16, J22, O12,O33, Q12, Q16

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Ethical Approval

The study was reviewed and approved by the Ethics Committee of the University of Hohenheim. All study participants gave their written consent to participate in the study. For study participants below the age of 18, consent was obtained from themselves and from their parents or guardians.

1 Introduction

Across the world, 821 million people do not have access to enough calories and are therefore undernourished (FAO et al., 2019). After years of decline, the number has increased in recent years – from 777 million people in 2015 (FAO et al., 2019). In addition, close to two billion people lack access to enough micronutrients and thus are malnourished, a phenomenon referred to as hidden hunger (IFPRI, 2016). The prevalence of both under- and malnutrition is particularly high among smallholder farmers (FAO et al., 2017; Pinstrup-Andersen, 2007). Therefore, agriculture-nutrition linkages have received much attention as a way to combat both under- and malnutrition (Dangour et al., 2013; Turner et al., 2013). This is also reflected in the term nutrition-sensitive agriculture. Such linkages are well recognised from a food quantity perspective: a high farm production raises the availability of food and therefore reduces undernutrition. In addition to the food quantity perspective, researchers are exploring agriculture-nutrition linkages from a food quality perspective, for example, by linking farm diversity with consumption diversity (Carletto et al., 2017; Fanzo, 2017; Jones, 2017; Sibhatu et al., 2015, Sibhatu & Qaim, 2018).

One agriculture-nutrition linkage has been forgotten more recently, however.[1] This is linking the ways of *how* food is produced with nutritional aspects (Dufour & Piperata, 2008; Zanello et al., 2017). This link is neglected despite the fact that the majority of smallholder farmers, especially in Africa, rely on hand tools for farming (FAO, 2016). This reliance on manual labour implies (seasonally) heavy physical work and high energy requirements. Much of this labour needs to be performed during the hunger season when the previous year's harvest is dwindling (Sitko, 2006). In contrast, farming systems that replace the requirements for human energy with non-human energy may significantly reduce the caloric requirements of farm family members. Such human energy replacing practises include agricultural mechanization, for example, which has received renewed interest in Africa (Adu-Baffour et al., 2018; Daum & Birner, 2017; Diao et al., 2014; Nin-Pratt & McBride 2014) and grown rapidly in various Asian countries (Takeshima, 2017; Wang et al., 2016). Another human energy replacing practice is the use of herbicides, which is gaining momentum across the developing world (Haggblade et al., 2017). For example, in Ethiopia, the use of herbicide per area ha of cereals grown has doubled between 2004 and 2014 to around 25% of the land cultivated (Tamru et al., 2017). Still, both the adoption of mechanization and herbicide is low in most African countries – with estimates for mechanization being around 1% of the farmers from the LSMS-ISA[2] countries Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda owning or hiring tractors (Sheahan & Barrett, 2017).

If people do not eat enough calories, a reduction of caloric requirements can contribute to reducing undernutrition. Household members who are most vulnerable to undernutrition, that is women and children, may benefit most. However, one also needs to assess the impact of mechanization on nutrition in view of the emerging "double burden" of malnutrition in developing countries. This term describes a situation that is "characterized by the coexistence of undernutrition along with overweight and obesity, or diet related non-communicable diseases, within individuals, households and populations, and across the life course" (WHO, 2019). This problem is of increasing importance not

[1] In this paper the term *forgotten* rather than *neglected* is used to refer to this agriculture-nutrition link since this link has received more attention in previous times. In Germany, for example, the Kaiser-Wilhelm-Institut (KWI) für Arbeitsphysiologie (*occupational physiology*; founded 1913) studied the link between farm technology, caloric requirements and labour productivity, partially motivated by war efforts (Heim, 2003). In 1948, the KWI became the Max-Planck-Institut (MPI) für Arbeitsphysiologie. In 1956, one of its departments became the MPI für Ernährungsphysiologie (*nutrition physiology*), which, for example, studied then link between farm technology and drudgery and provided assistance for an FAO report on nutrition and work efficiency (FAO, 1957).

[2] Living Standards Measurement Study – Integrated Survey on Agriculture conducted by the World Bank.

only in developed but also in developing countries (Dufour & Piperata, 2008; Popkin, 2001; Steyn & Mchiza, 2014). Research also indicates that the double burden is no longer an exclusively urban phenomenon (Prentice, 2005; Shafique et al., 2007; Min et al., 2018). For example, Doku et al. (2017) find that 16% of rural women in Ghana are obese. Roemling and Qaim (2012) have shown for Indonesia that obesity is rising faster in rural than in urban areas, especially among women, due to changes in food consumption and physical activity levels (using occupation as a proxy) as well as undernutrition in early childhood. Jones-Smith et al. (2012) argue that with access to "cheap calories" (derived from food such as staple grains and sugar), the burden of overweight is shifting to the global poor, many of whom are smallholder farmers. Importantly, obesity may co-exist with micronutrient deficiencies, especially if it is the result of a poor diet. If the diets of farm families are not deficient in energy (though they may be deficient in micro-nutrients), mechanization may contribute to the obesity problem, if it reduces energy requirements and if farm families do not adjust their diets accordingly. However, one needs to take into consideration that, for the following reasons, the relations between mechanization and energy requirements are even more complex:

- Mechanizing one farming practice may have implications on subsequent farming practices that are not mechanized. For example, if only land preparation is mechanized (as is often the case in early phases of mechanization – as shown by Binswanger (1986)), the size of the cultivated area may increase, which can increase the work load in subsequent non-mechanized activities, such as weeding and harvesting (Daum et al., 2019). This will increase the energy requirements of the household members involved in those activities. Mechanized land preparation may, however, also lead to reduced weed growth (Nyamangara et al., 2014), which would reduce the time and the energy requirements for weeding if land size is held constant.
- There is a substitution effect, as time saved due to mechanization can be shifted to alternative time-uses, which may require more or less energy than the energy saved by mechanization.
- Different household members (male and female adults and male and female children) may be affected differently by mechanization, depending on the gender and age division of labour (Blackden & Wodon, 2006; Doss et al., 2001). Mechanization may change this division of labour. Moreover, the substitution effect mentioned above may differ by gender and age. While the gender effects of interventions in agriculture have received increasing attention in recent years (Doss, 2001; Farnworth et al., 2016), the effects on children have been largely neglected, even though approximately 60% of all child labour takes place in agriculture (ILO, 2019).
- There are differences between mechanization by animal draught power and mechanization by tractors. On the one hand, animals (unlike tractors) require care-intensive activities, such as feeding, throughout the year. On the other hand, it might be economic to use animals for a wider range of labour-saving (and, thus, energy-saving) activities than it is to use tractors. Moreover, the differentiation by gender and age and the substation effects may be different depending on whether animal draught power or tractors are used.

In view of this complexity, there is a need to better understand whether and to what extent mechanization will affect the energy requirements of different types of household members and how these changes will, in turn, reduce or aggravate the multiple problems of malnutrition. Collecting detailed time-use and nutrition data for this purpose is, however, a major challenge. To capture the substitution effect, it is essential to cover all types of farm and non-farm activities as well as time use for both work and leisure. To assess the gender and age division of labour, it is essential to collect time use and nutritional data from different type of household members. To our knowledge, these complex and gender-sensitive linkages between mechanization, time use, human energy requirements and nutritional outcomes have not been studied, so far.

The present study aims to contribute to addressing this knowledge gap by taking a rural area in Zambia as an example. The study has the following three main objectives: firstly, to assess the relevance of the agriculture-nutrition link caused by changing farm technologies (using agricultural mechanization as an example) by studying the association between different mechanization levels and caloric energy requirements in smallholder farming households. The second objective is to establish a proof-of-concept for the method of converting time-use data into energy requirements if time use data are collected in real time by research subjects themselves using a smartphone app. The third objective is to identify whether differences in energy requirements related to mechanization are linked with changes in diets and to assess whether those changes are likely to improve or worsen nutritional outcomes.

The study was designed to compare the energy requirements of household members in rural Zambia in farms that are characterized by three different levels of mechanization used for land preparation: (1) hand tools; (2) animal drought power; and (3) tractors. Data was collected using a novel data collection method: a smartphone application called Timetracker, which enables individual household members record their time-use in real time. Timetracker has the advantage to reduce the recall bias that is a major problem in recall-based questionnaires (Arthi et al., 2016; Daum et al., 2019). The Timetracker app is picture-based, which makes it possible to collect data from respondents with low levels of literary and from children. Since the Timetracker was designed to capture 88 different farm and household activities, the app is well suited to examine the substitution effect. Data was collected during one entire farming season to so as to capture the impact of mechanizing land preparation on sub-sequent farming activities. Timetracker also includes a module that makes it possible to collect basic data on nutrition, as further detailed below.

To convert the data collected using Timetracker into daily energy requirements, we used the "Ainsworth's Compendium of Physical Activities" (2011), which compiles the energy demand of approximately 600 different physical activities. Such a conversion approach was pioneered by Tudor-Locke et al. (2009), who translated the physical activities of people from the United States of America into energy requirements. More recently, the approach was used by Deyaert et al. (2017) to calculate the energy requirements of different occupations in Belgium. Van der Ploeg et al. (2010) found that the energy requirements calculated by such an approach closely resemble the energy requirements measured with accelerometers.

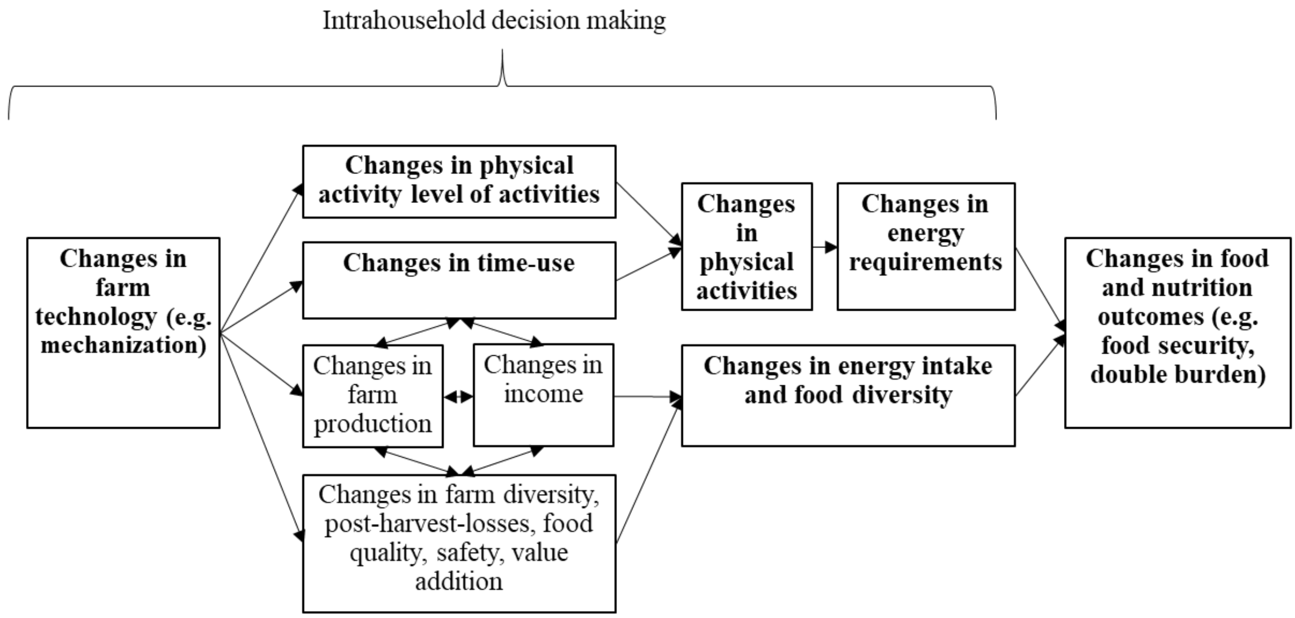
As further explained in the methods section, we collected data for 2,790 days of time use, out of which 1674 used for this since the paper focuses on land preparation, weeding and harvesting/processing, from 62 households. Considering that we were only able to use cross-sectional data and that the number of households included in our study is limited, this paper should be understood as a proof-of-concept case study. Establishing causality would require panel data and a larger sample size. According to current standards of impact assessment applied in economics, a randomized control trial would be preferable. However, in the case of agricultural mechanization using tractors, conducting a randomized control trial is costlier than it is for other interventions (such as, e.g., nutrition or deworming programmes). In view of the complexity of the mechanization-nutrition linkages pointed out above, it appears useful to conduct an explorative study such as this one prior to conducting a large-scale randomized controlled trial.

The paper is structured as follows: In section 2, conceptual considerations on agricultural mechanization and food and nutrition pathways are presented. In section 3, the Timetracker app, the sampling strategy and sample characteristics are outlined. In addition, the conversion of time-use data into physical activity ratios and energy requirements is explained and the empirical model is presented. In section 5, the differences of energy requirements are analysed by gender and mechanization for different seasons. Energy requirements are also compared with food consumed. Section 6 discusses the findings and presents our conclusions.

2 Conceptual Considerations and Literature Review

Figure 1 displays how changes in farm technology and practices (such as agricultural mechanization) can affect nutritional outcomes in farm households through different pathways, all of which are determined by intra-household decision making. This paper focuses on changes in physical activities (or drudgery) and time-use, which affect food and nutrition outcomes by potentially influencing both physical activity levels and, subsequently, energy requirements. The linkages analysed are bolded in figure 1.

Figure 1. Conceptual framework



As discussed above, this link has been largely neglected in the recent literature on agriculture-nutrition linkages. In addition to this link, there are other pathways by which changes in farm technologies and nutrition are interlinked. A well-established pathway is the income or production pathway: If new farm technologies allow farm households to produce more (by cultivating more land, reaching higher yields or reducing harvest and post-harvest losses), they can consume or sell more, which may result in higher food consumption and better diets. This link was important during the Asian Green Revolution when rising farm productions led to higher dietary energy consumption (Evenson & Gollin, 2003; Headey & Hoddinott, 2016). Similarly, changes in farm technologies that allow for value addition and higher selling prices may also enhance food and nutrition outcomes (Malabo Montpellier Panel, 2018). New farm practices and technologies can also affect food safety and quality. For example, applying pesticides more precisely can reduce food contamination (Carvalho, 2006). Better drying, cooling, storage and transportation technologies can help to preserve food (and nutrients) and reduce contamination with fungus such as aflatoxins (Fanzo, 2014). Guaranteeing food safety may give farmers access to markets paying higher prices (Chege et al., 2015; Handschuch et al., 2013). Changes in farm technology and practices can also affect farm diversity. For example, farmers may focus on crops that are easy to mechanize such as maize (Kansanga et al., 2018), a link that has been largely neglected. Changes in farm diversity can then influence consumption diversity, if farmers do not counterbalance reduced farm diversity by buying food from markets. The farm diversity-consumption diversity link has been well studied (Carletto et al., 2017; Fanzo, 2017; Jones, 2017; Sibhatu et al., 2015, Sibhatu & Qaim, 2018). There is also a time-use pathway, which has received attention only recently. For example, changes in farm technology and practices can influence the time available for cooking, which can then influence household nutrition (Johnston et al., 2018). Changes in farm technology and practices can also influence the possibility to conduct off-farm work and derive an income from that.[3] All of the above links can influence each other and they may involve feedback loops. The overall food and nutrition outcomes are also affected by social and cultural factors as they influence gender roles in farm households and may have other implications, e.g., regarding the substitution effect.

[3] There may also be yet other pathways, for example, an employment pathway: if mechanization leads to fewer employment opportunities for labourers, this can affect the nutrition in their households.

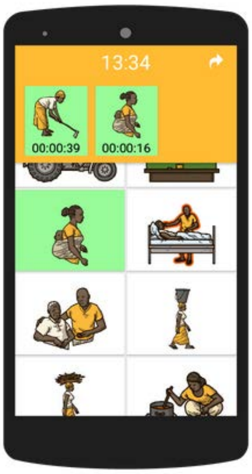
3 Methods

Section 3.1 describes how time-use and nutrition data was collected and Section 3.2 explains how the time-use data was converted into daily energy requirements. Section 3.3 presents the empirical model used to analyse the data.

3.1 Collection method for time-use and nutrition data

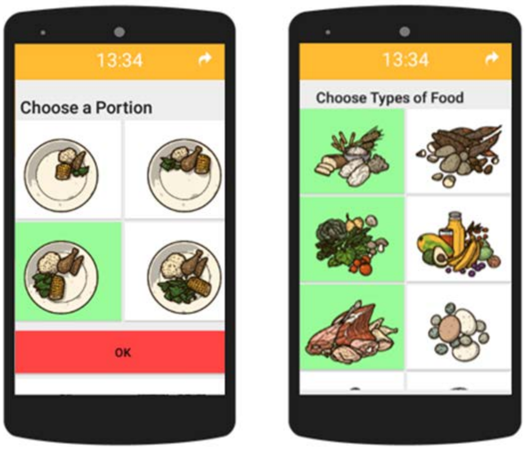
Collecting reliable time-use data is challenging in developing countries. Direct observations have been used but suffer from observer bias and are not feasible for longer time periods and larger samples (Zanello et al., 2017). Questionnaires are affected by a recall bias and they often group various physical activities together. For example, shelling, milling, winnowing and grinding are aggregated for analysis into one processing activity (Arthi et al., 2016; Daum et al., 2019). Time-use diaries reduce recall bias but are not feasible when respondents are not literate and they are coarse as they are based on pre-defined time slots – ranging from 15 to 30 minutes. To avoid these problems, the data used for this study was collected using a novel approach: a picture-based smartphone application called Timetracker (see Daum et al., 2018; Daum et al., 2019 for a detailed discussion on advantages and disadvantages). The Timetracker app allows participants to record time-use in real time, which eliminates the recall bias. Daum et al. (2019) has shown that this leads to more accurate measurements of time use compared to recall based methods of data collection. Timetracker uses only visual tools to reduce selection bias, especially to ensure that persons with low literacy levels as well as children can participate. The app has a simple design, which is displayed in figure 2.

Figure 1. Interface of the time module. Own illustration.



Participants click on a picture of the respective physical activity when they start to carry out this activity (see figure 2) and click again on this picture when they stop the activity. The Timetracker allows participants to record up to three simultaneous activities, but this paper uses only the data from the primary activities because respondents typically listed second and third activities that either have no additional energy demands (e.g., listening to the radio) or relatively lower energy demands (e.g., chatting). A "plug-in" has been designed if the selected activity is "eating" (see figure 3). In this case, a window pops up where respondents can record the perceived quantity of food consumed by clicking of one of four differently filled plates. In a second pop-up window, twelve different food groups are shown. The grouping follows the classification suggested by Swindale & Bilinsky (2006), which makes it possible to calculate food diversity scores.

Figure 3. Interfaces of the food and nutrition module. Own illustration.



3.2 Sampling of farm households

The time-use data was obtained from 62 farm households in the Eastern Province of Zambia. The Eastern Province is dominated by smallholder farmers, who cultivate on the average 2.3 ha of land, mostly, maize, cotton, sunflowers, groundnuts and tobacco (IAPRI, 2016). Households rely mostly on manual labour and draught animals, but there are also households who own or hire mechanical power for land preparation (IAPRI, 2016). The 2018 Global Hunger Index ranks Zambia 115th of 119 assessed countries and reports its status as alarming.[4] At the national level, between 41% and 46% of all households experience undernourishment. In the Eastern Province, most indicators for undernutrition are below the national average (Mukuka & Mofu, 2016).

To select the 62 farm households, a two-stage-random-sampling approach was used based on the sample of the 2014/2015 round of the nationally representative Zambian Rural Agricultural Livelihood Survey (RALS). In a first step, four survey clusters, which are geographical areas comprising one or several neighbouring communities, were randomly selected based on the condition that at least five households were non-mechanized, five households used animals and one household was mechanized. In a second step, five non-mechanized households, five households using animal draught power (ADP) and five to six mechanized households were randomly selected from each of these clusters. The households will henceforward be abbreviated as "manual-, animal- and tractor-households." To make it possible to assess the gender and age division of labour, households were selected based on the condition that there were at least one adult male, one adult female and one child in the household.[5] In case the households included in RALS were exhausted based on these restrictions, additional households were selected from lists of the District Agriculture and Cooperatives Offices. In total, 20 manual-, 20 animal- and 22 tractor-households were selected. Table 1 shows the sample characteristics of the three different groups.

[4] https://www.globalhungerindex.org/zambia.html

[5] Using this rule, we essentially excluded female-headed households. The reason was that we wanted to focus on gender division of labour in male-headed households since our sample was too small to assess this difference.

Table 1. Sample Characteristics

Variable	Manual (I)	Animal (II)	Tractor (III)	P-Value	Intergroup Comparison I vs II	I vs III	II vs III
Household characteristics							
Household size	6.6 (1.6)	7.8 (2.3)	6.7 (2.1)	0.122	NS	NS	NS
Gender head male (%)	95% (0.2)	100% (0)	95% (0.4)	0.622	NS	NS	NS
Age	49.7 (17.0)	45.1 (11.2)	47.3 (13.8)	0.594	NS	NS	NS
Education level head (0-18)	6.8 (3.2)	8.5 (3.5)	10.5 (4.2)	0.008	NS	***	NS
Agronomic characteristics							
Land cultivated (ha)	2.3 (1.1)	4.8 (3.9)	8.4 (5.9)	0.000	NS	***	**
Land owned (ha)	2.5 (1.8)	5.9 (6.6)	19.8 (30.9)	0.009	NS	***	**
Crop diversity	3.1 (1.1)	3.7 (1.1)	3.5 (1.0)	0.161	NS	NS	NS
Frequency of animal draught weeding	0.32 (0.4)	0.69 (0.5)	0.51 (0.4)	0.028	**	NS	NS
Maize yield (tons/ha)	1.91 (1.6)	2.63 (1.6)	3.55 (1.9)	0.013	NS	***	NS
Fertilizer per ha cultivated (kg)	110 (135)	190 (148)	216 (206)	0.152	NS	NS	NS
Pesticide per ha cultivated (l)	1.5 (4.6)	8.8 (14.8)	5.4 (11.5)	0.131	NS	NS	NS
Tropical livestock unit[1]	0.8 (1.0)	7.4 (7.9)	6.4 (8.0)	0.004	***	**	NS
Hired labour (hours per cultivated ha)							
Land preparation	4 (12)	7 (25)	4 (10)	0.801	NS	NS	NS
Weeding	5 (24)	14 (49)	21 (47)	0.488	NS	NS	NS
Harvesting	9 (39)	8 (25)	17 (35)	0.637	NS	NS	NS
Socio-economic characteristics							
Log income	7.8 (1.6)	9 (1.2)	10.3 (1.0)	0.000	**	***	***
Share off-farm income (%)	35 (58)	17 (31)	33% (31)	0.315	NS	NS	NS
Month food shortage	2.4 (0.4)	1.5 (0.4)	1.2 (0.4)	0.089	NS	*	NS
Distance to nearest market (km)	6.7 (5.2)	6.6 (7.0)	4.4 (7.0)	0.425	NS	NS	NS
Sample size	20	20	22				

Standard deviation in brackets. Differences of means are based on Tukey post hoc tests and are indicated with *, **, and ***, which denote significance of mean differences at the 10%, 5%, and 1% level, respectively. NS=not significant. [1]Tropical Livestock Unit with the following weights: cattle = 0.7, sheep = 0.1, goats = 0.1, pigs = 0.2, chicken = 0.01.

In each household, the male household head, spouse and one child (alternating between boy and girls) recorded data with the Timetracker app for three days at five points of the 2016/2017 farming season. For this study, participants were provided with smartphones with the pre-installed Timetracker app. They also received water-proof poaches to carry the smartphone. Participants received a training on how to record data and then recorded data for three days at five different points of the 2016/2017 farming season (Daum et al., 2019; Daum et al., 2018). Data was not collected in the four communities in parallel but one after the other so that in total data from 60 days was obtained. This resulted in 2790 individual data days for which time use and nutrition data were collected. In this paper, the focus is on land preparation, weeding and harvesting/processing, which are considered to be the most relevant labour- and control-intensive farming steps (Binswanger, 1986), thus using 1674 data days. In this paper, averages of the three data days collected at each point of the farming season are used to avoid daily outliers.

3.3 Conversion of time-use data to energy requirements

Daily time-use data was translated into energy requirements as described in this section. The average daily physical activity ratios were calculated based on the metabolic equivalent tasks (MET) of Ainsworth et al. (2011). If METs for specific tasks were unavailable, the physical activity ratios (PAR) calculated by FAO et al. (2004) were used, which are obtained based on the same approach. We primarily rely on Ainsworth MET since their compendium is more comprehensive. Subsequently, both will be referred to as physical activity ratios and abbreviated as PAR, as both concepts essentially have the same meaning and physical activity ratios is the more tangible expression (for example, say that a PAR of 2 means that twice as much energy is required for this activity as for sleeping with a PAR of 1). The full table of PARs for different daily activities and their descriptions can be found in the appendix. Table 2 illustrates this approach.

Table 2. Illustrative Overview of the Conversion of Time-use to Daily Energy Requirements

Activity	Hours	PAR	Ainsworth Code	Hours x PAR	Average PAR	Daily energy requirements
Sleeping	8	1.0	07030 ("sleeping")	7.6	60.3/24 = **2.5**	BMR x Average PAR = 1559 x 2.5 = **3898**
Hoeing	6	5.0	08241 ("…hoe, moderate-vigorous")	30		
Chatting	4	1.3	07060 ("… talking ...")	5.2		
Walking	4	3,5	17190 ("walking, …moderate)	14		
Hygiene	1	2.0	13050 ("showering, toweling off…")	2		
Eating	1	1.5	13030 ("eating, sitting")	1.5		
Total	24			60.3		

[1] For BMR we assume a height of 170 cm, a weight of 60 kg and an age of 35 years for males.

To get an idea into how much caloric energy is required by an average person with a given daily physical activity ratio, these ratios were multiplied with basal metabolic rates (BMR) based on average values. This is for illustrative purposes and all statistical analysis will be based on PARs. The BMR captures the energy needed to maintain human life when resting, for example to ensure cell functions, maintain body temperature and support cardiac and respiratory muscles as well as brain functioning (FAO, 2014). BMRs are mainly determined by age, gender, height and weight. For the average person, the assumptions shown in table 3 were used. The age levels reflect the average across our sample. The heights are chosen in line with the average heights for males in Zambia measured by Blum and Baten (2012). Weights are assumption from experts interviewed for this study.

Table 3. Assumptions for determinants of BMR for average people

Determinant	Male adult	Female adult	Male child	Female child
Height (cm)	170	160	160	155
Weight (kg)	65	55	50	45
Age (years)	35	35	16	15
BMR[6]	1559	1307	1442	1296

3.4 Empirical methods

Different variables of interest are included in the empirical analysis: daily physical activity ratios, the share of non-basal metabolic energy requirements caused by farming activities, the physical activity ratios related to farming and the time spent farming. As the sampling was stratified by communities and households with three different members each, a multivariate linear mixed model (Piepho et al., 2003) was used to calculate the dependence of these variables on mechanization:

[6] Calculated using http://www.bmi-calculator.net/bmr-calculator/metric-bmr-calculator.php#result

$$y_{ijkl} = \mu + c_j + h_l + \pi_i + \gamma_k + \pi\gamma_{ik} + \varepsilon_{ijkl},$$

(1)

where y_{ijkl} is the outcome variable for a person in community *j*, from mechanization group *i*, in household *l* with gender *k* and

μ is the constant,

c_j is the effect of the *j-th* community,

h_l is the effect of the *l-th* household,

π_i is the effect of the *i-th* mechanization group,

γ_k is the effect of the *k-th* gender,

$\pi\gamma_{ik}$ is the interaction of gender and mechanization group.

ε_{ijkl} are the error effects associated with y_{ijkl}. ε_{ijkl} are assumed to be normal distributed with mean zero and variance $\sigma^2{}_{\varepsilon}$. To account for the correlation of persons within the same household, h_l was modelled as a random effect with mean zero and variance $\sigma^2{}_h$. Normal distribution of residuals and homogeneity of variance were assessed graphically by the inspection of quantile-quantile-plots of residuals and the scatter plots of residuals versus predicted values, respectively. Model parameters were estimated using the restricted maximum likelihood method (REML) of the GLIMMIX procedure in SAS (Version 9.4). Model effects were tested for significance in sequential Wald-type F-tests. Non-significant effects were excluded from the model. The levels of factors found significant in the F-test were compared by pairwise Tukey-tests. The results of pairwise comparisons were visualized as letter display. Throughout the entire statistical analysis, the significance level of α = 10% was used. Covariates were controlled for having influence on the share of energy caused on farming. For this purpose, model (1) was amended by several covariates and multiple linear regression was performed, hence the regressors entered linearly and no interactions with gender or power group were fitted. Non-significant covariates were removed from the model by backwards elimination. The threshold for remaining in the model was a p-value of 10% in the F-test. To investigate the relationship of daily physical activity ratio and food intake, average daily portion size was used as response variable in model (1). In addition, the model was amended with power group- and gender-specific slopes for a regression on daily physical activity ratio. A household specific random deviation from the intercept and slope was fitted.

4 Results

Table 4 shows average daily physical activity ratios during the three different time periods of land preparation, weeding and harvesting/processing. The table shows that male and female adults in households using tractors for land preparation have significantly lower physical activity ratios than households using manual labour (17% and 20% less, respectively) and that males have significantly lower ratios compared to their counterparts in animal-households (16% less) based on model (1). The average male described above would need 533 calories less and the average female would need 483 calories less per day when using tractors rather than manual labour. In animal-households, the values are not significantly different compared to manual-households for males, but they are for females indicating that females benefit more from the adoption of animal draught power than males. The tables also show that while men and women have similar physical activity rations in manual-households, women have significantly lower values in animal-households. Average adult women in such households needs 867 calories less per day than their male counterparts. In tractor-households, both girls and boys have significantly higher physical activity ratios than female but not than male adults. Importantly, the caloric values shown are based on a stylized woman who is not breastfeeding. With full breastfeeding, the daily energy requirements would be 675 kcal/day higher; with partial breastfeeding they would be 460 kcal/day higher (FAO, 2004). Gender differences in daily caloric energy requirements (but not average PAR) thus level out to some extent when considering lactation. During the weeding period, men in tractor-households still have significantly lower ratios than their counterparts in manual-households (11% less) and animal-households (15% less). This is not the case for women. During harvesting/processing, males in animal-households have the highest physical activity ratios, while males in tractor-households have a 23% lower value. In such households, the average (non-lactating) females need 1058 calories less than their male counterparts.

Table 4 shows not only daily physical activity ratios, including farming activities, but also activities such as transportation, domestic chores, personal care (e.g., sleeping, personal hygiene and eating) and social life (e.g., resting, chatting, and using media).

Table 4. Energy requirements and physical activity levels based on collected time use data during different periods of the farming season

	Manual				*Animal*				*Tractor*				*(1)-(3) (%)*				*(2)-(3) (%)*			
	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G
Land preparation																				
Sample size	60	60	36	24	60	60	27	33	66	66	33	33								
Average PAR	2,29^{Aa}	2,20^{Aa}	2,23^{Aa}	2,10^{Aa}	2,26^{Aa}	2,05^{ABa}	2,13^{Aa}	2,15^{Aa}	1,95^{Bab}	1,83^{Bb}	2,12^{Aa}	2,21^{Aa}	**-17**	**-20**	-5	5	**-16**	-12	0	3
Kcal/day*	3593	2875	3216	2722	3546	2679	3071	2786	3060	2392	3057	2864	**-17**	**-20**	-5	5	**-16**	-12	0	3
Weeding																				
Sample	60	60	33	18	60	60	27	30	66	66	30	33								
Average PAR	2,31^{Aa}	2,27^{Aa}	2,51^{Aa}	2,32^{Aa}	2,40^{Aa}	2,26^{Aa}	2,33^{Aa}	2,28^{Aa}	2,09^{Ba}	2,09^{Aa}	2,31^{Aa}	2,32^{Aa}	**-11**	-9	-9	0	**-15**	-8	-1	2
Kcal/day*	3624	2967	3619	3007	3766	2954	3360	2955	3279	2732	3331	3007	**-11**	-9	-9	0	**-15**	-8	-1	2
Harvesting/processing																				
Sample	57	60	36	24	60	60	27	33	60	60	27	33								
Average PAR	2,01^{Ba}	2,06^{Aa}	2,27^{Aa}	1,97^{Aa}	2,39^{Aa}	2,06^{Ab}	2,34^{Aab}	2,25^{Aab}	1,95^{Ba}	1,95^{Aa}	2,00^{Aa}	1,97^{Aa}	-3	-6	-14	0	**-23**	-6	-17	-14
Kcal/day*	3154	2692	3273	2553	3750	2692	3374	2916	3060	2549	2884	2553	-3	-6	-14	0	**-23**	-6	-17	-14

Males (M), females (F), boys (B) and girls (G). *Required kcal/day is calculated as average PAR x BMR, which is based on the assumptions described above. Mean estimates and pairwise Tukey-tests are based on model (1). Upper case letters refer to difference by mechanization, lower case letter refer to difference by gender. Means that share a common letter do not differ at 10% significance level. Significant % differences are bolded.

Table 5 shows the average daily share of non-basal metabolic energy requirements caused by different activities. The share is determined by time spent for and intensity of the respective activity. What is notable are the high shares of farming, transportation and domestic chores.

Table 5. Daily share of non-basal metabolic energy requirements for different activities across individuals

	Manual				*Animal*				*Tractor*			
	M	F	B	G	M	F	B	G	M	F	B	G
Land preparation												
Farming and related activities	44	29	15	13	35	18	19	15	28	13	11	15
Off-farm work and seasonal labor	0	0	0	0	0	1	0	0	3	3	0	0
Transportation	18	13	14	21	27	10	16	19	20	11	21	17
Education	0	0	3	6	0	0	10	4	0	0	3	5
Domestic	3	24	21	17	1	36	12	17	3	29	20	17
Personal care	20	20	23	21	20	22	21	22	24	26	24	22
Social life	16	13	24	21	17	13	21	24	22	18	20	24
Weeding												
Farming and related activities	46	41	39	34	38	33	35	35	36	31	25	30
Off farm work and seasonal labor	0	0	0	0	1	0	0	0	0	2	0	0
Transportation	16	12	15	15	28	12	14	19	24	13	23	19
Education	0	0	1	0	0	0	1	0	0	0	0	0
Domestic	2	18	12	15	1	26	14	10	1	18	11	13
Personal care	20	20	19	20	18	20	22	20	23	24	23	21
Social life	16	10	16	15	13	9	14	16	16	12	18	16
Harvesting/processing												
Farming-and related activities	35	27	23	12	25	26	27	13	29	25	13	16
Off farm work and seasonal labor	0	0	0	1	2	0	0	6	3	1	0	0
Transportation	21	11	14	16	36	10	18	17	19	9	19	10
Education	0	1	5	8	0	0	3	4	0	0	5	5
Domestic	2	25	17	24	2	28	7	17	3	25	14	20
Personal care	25	23	22	24	21	25	20	22	25	25	27	26
Social life	17	13	19	16	15	10	23	22	20	15	23	23

Males (M), females (F), boys (B) and girls (G).

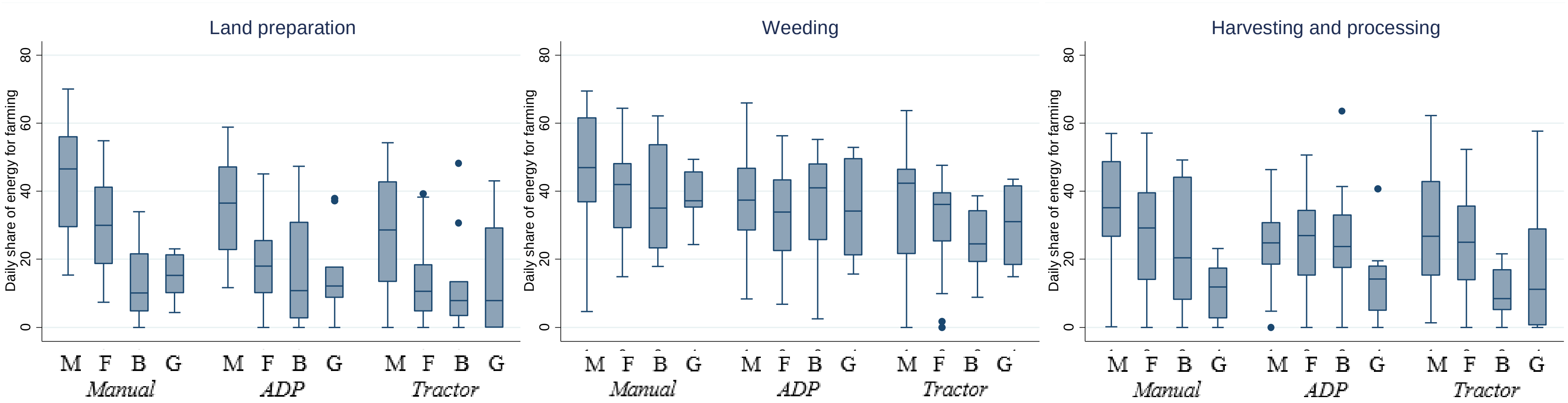
Expectedly, mechanization primarily affects farming activities, although changes in time and energy spent on farming affect the time available for other activities, which may be more or less energy demanding. Table 6 and figure 4 show the share of energy requirements caused by farming activities alone. Noteworthy are gender differences. For example, during land preparation, adult males have almost double the energy needs caused by farming compared to all other household members. As expected, mechanization does reduce the share of energy required for farming. For example, during the land preparation period, males in tractor-households have significantly lower shares than males in manual-households. The difference is 56%, which is more than three times as high as the difference in daily PAR (see table 4). This also suggests that the labour reducing effects of mechanization are partially reduced as time is "shifted" to other activities, of which some, such as transportation, are similarly energy demanding. This can also be observed during the harvesting/processing season, when males in animal-households have lower values compared to manual-households. However, as shown in table 4, they have the highest daily physical activity ratios. This suggests that time and energy that is not needed for farming is used for other activities with high energy requirements. Table 5 suggests that these may be transportation activities, as animal-households tend to provide ox-carts services.

Table 6. Share of non-basal metabolic energy requirements caused by farming

	Manual				*Animal*				*Tractor*				*(1)-(3) (%)*				*(2)-(3) (%)*			
	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G
Land preparation	44^{Aa}	29^{Ab}	15^{Ac}	13^{Ac}	35^{Ba}	18^{Bb}	19^{Ab}	15^{Ab}	28^{Ba}	13^{Bb}	11^{Ab}	15^{Ab}	**-56**	**-136**	-40	15	-23	-47	-79	6
Weeding	46^{Aa}	41^{Aa}	39^{Aa}	34^{Aa}	38^{ABa}	33^{ABa}	35^{ABa}	35^{Aa}	36^{Ba}	31^{Ba}	25^{Ba}	30^{Aa}	**-28**	**-32**	**-53**	-15	-5	-6	-39	-16
Harvesting/ processing	35^{Aa}	27^{Aab}	23^{ABbc}	12^{Ac}	25^{Ba}	26^{Aa}	27^{Aa}	13^{Ab}	29^{ABa}	25^{Aab}	13^{Bc}	16^{Abc}	-20	-9	-85	25	15	-4	**-116**	16

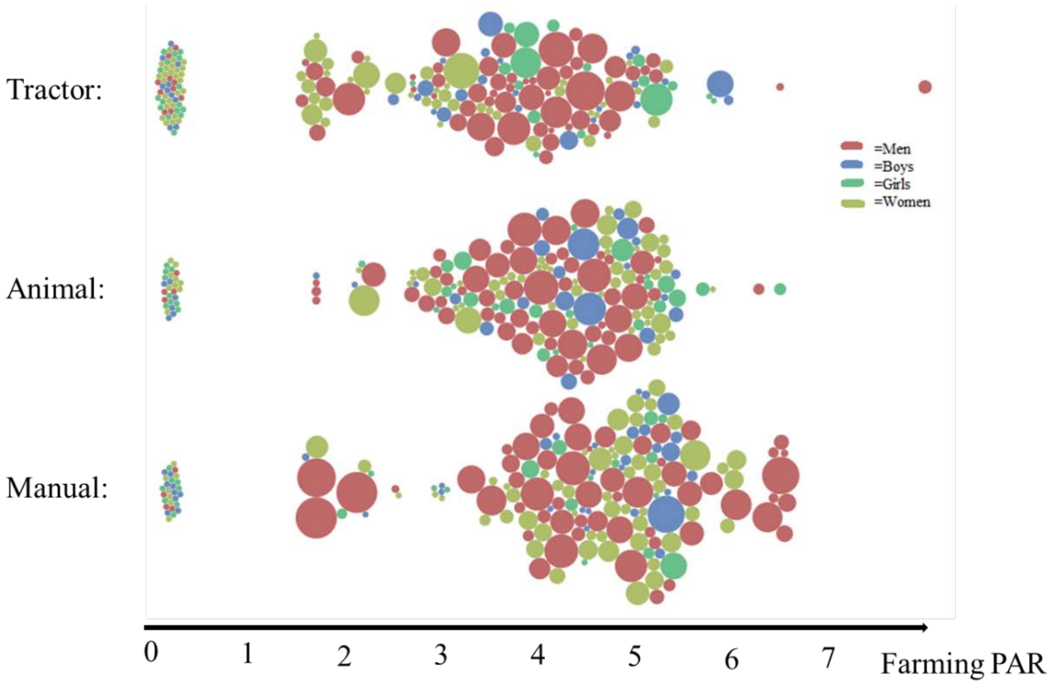
Males (M), females (F), boys (B) and girls (G). Mean estimates and pairwise Tukey-tests based on model (1). Upper case letters refer to differences by mechanization, lower case letter refer to difference by gender. Means that share a common letter do not differ at 10% significance level. Significant % differences are bolded.

Figure 4. Boxplots displaying share of non-basal metabolic energy requirements caused by farming



The differences of daily energy requirements caused by farming can be due both to differences in time spent on farming and to differences in physical activity ratios while farming. These effects are shown in table 7 for all three time periods. Figure 5 visualizes these effects for the land preparation season.

Figure 5: Effects of different levels of mechanization on time spent on farming and PAR for the land preparation season



Each circle represents one individual. The top row shows individuals from tractor-households, the second row shows individuals from animal-household and the third row shows individuals from manual-households. The position of the circle on the horizontal axis show the individual's average physical activity ration during farming activities. The size of the circle (radius) represents the individual's time spent on farming activities by gender during land preparation. The graph was created with https://rawgraphs.io

Table 7. Time spent on farming activities and associated average physical activity ratios

	Manual				*Animal*				*Tractor*				*(1)–(3) (%)*				*(2)- (3) (%)*			
	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G
Land preparation																				
Farming PAR	4,48^{Aa}	4,39^{Aa}	4,37^{Aa}	3,99^{Aa}	3,75^{Ba}	4,06^{Aa}	3,99^{Aa}	3,89^{Aa}	3,60^{Ba}	2,90^{Bb}	3,78^{Aac}	4,45^{Ac}	**-24**	**-51**	-16	10	-4	**-40**	-6	13
Time share	22^{Aa}	12^{Ab}	5^{Ab}	5^{Ab}	17^{ABa}	6^{Bb}	10^{Ab}	6^{Ab}	14^{Ba}	5^{Bb}	4^{Ab}	6^{Ab}	**-57**	**-137**	-17	24	-25	-28	-127	0
Weeding																				
Farming PAR	4,39^{Aa}	4,68^{Aa}	4,58^{Aa}	4,64^{Aa}	4,45^{Aa}	4,49^{ABa}	4,45^{Aa}	4,61^{Aa}	3,81^{Ba}	4,21^{Ba}	4,46^{Aa}	4,48^{Aa}	**-15**	**-11**	-3	-4	**-17**	-7	0	-3
Time share	24^{Aa}	21^{Aa}	21^{Aa}	18^{Aa}	21^{Aa}	17^{Aa}	20^{Aa}	17^{Aa}	20^{Aa}	16^{Aab}	13^{Ab}	16^{Aab}	-19	-26	-55	-11	-5	-2	-50	-9
Harvesting/processing																				
Farming PAR	3,40^{Aa}	3,72^{Aa}	4,06^{Aa}	3,88^{Aa}	3,75^{Aa}	3,65^{Aa}	4,26^{Aa}	3,78^{Aa}	3,34^{Aa}	3,38^{Aa}	2,94^{Ba}	2,74^{Ba}	-2	-10	**-38**	**-40**	-12	-8	**-45**	**-36**
Time share	21^{Aa}	16^{Aab}	13^{Abc}	6^{Ac}	15^{Aa}	15^{Aa}	16^{Aa}	8^{Ab}	16^{Aa}	15^{Aab}	8^{Ab}	9^{Ab}	-26	-7	-62	35	9	1	-96	16

Mean estimates and pairwise Tukey-tests based on model (1). Upper case letters refer to difference by mechanization, lower case letter refer to difference by gender. Means that share a common letter do not differ at 10% significance level. Significant % differences are bolded.

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There are other factors that may influence energy requirements for farming besides the ones considered so far - which were (based on model (1)) community, mechanization, household and gender. Such factors may include the use of hired labour and land size cultivated. In this section, some of these factors are controlled for, focusing on the share of non-basal metabolic energy requirements caused by farming as an outcome variable.

Table 8. Share of non-basal metabolic energy requirements caused by farming (Results of multiple linear regression models)

	Land preparation				Weeding				Harvesting/processing			
	Estimate	DF	F-value	p-value	Estimate	DF	F-value	p-value	Estimate	DF	F-value	p-value
Community	**- ‡**	**55.2**	**7.49**	**0.0003**	- ‡	51.3	1.55	0.2116	**- ‡**	**56.1**	**4.38**	**0.0077**
Mechanization	**- ‡**	**67.1**	**4.75**	**0.0118**	- ‡	42.4	0.27	0.7639	- ‡	54.3	0.71	0.4983
Gender (M, F, B, G)	**- ‡**	**136**	**29.70**	**<.0001**	**- ‡**	**136**	**2.90**	**0.0376**	**- ‡**	**130**	**11.06**	**<.0001**
Gender*mechanization	**- ‡**	**135**	**2.22**	**0.0446**	- ‡	124	0.30	0.9340	- ‡	124	1.58	0.1599
Cultivated land	-0.03	49.9	0.01	0.9330	**-0.94**	**51.5**	**14.87**	**0.0003**	0.52	50.7	1.16	0.2857
Household size	-0.62	55.1	1.48	0.2296	-0.00	47.8	1.13	0.2928	-0.61	49.1	0.67	0.4157
Maize yield	-	-	-	-	-	-	-	-	0.00	48.3	0.52	0.4723
Hired labour	0.00	47.7	0.04	0.8382	-0.00	47.6	1.70	0.1985	-0.00	52.5	0.91	0.3451
Off-farm income	-0.00	50.8	0.40	0.5283	**-0.00**	**52**	**3.59**	**0.0638**	-0.09	54.5	1.96	0.1672
Months food shortage	-0.22	51.3	0.11	0.7367	0.35	48.9	0.33	0.5700	-0.72	52.3	0.74	0.3938
Education head	0.05	46.5	0.04	0.8512	0.29	44.7	0.57	0.4540	0.09	43.2	0.04	0.8377
HH pregnancy	-4.27	166	0.76	0.3833	-2.00	162	0.15	0.6959	5.13	147	1.00	0.3200
Fertilizer	-	-	-	-	**-0.01**	**49.9**	**3.15**	**0.0822**	-0.00	43.2	0.14	0.7058
Pesticides	-	-	-	-	0.01	39.1	0.01	0.9157	-	-	-	-
Input costs	-0.00	48.9	0.20	0.6528	0.00	44.4	0.10	0.7490	-0.00	48	0.99	0.3239
# ADP weeding	-	-	-	-	-3.49	49.5	2.11	0.1529	-	-	-	-
Tropical livestock unit	0.14	52.3	0.70	0.4080	-0.01	38.1	0.00	0.9535	-0.03	41.1	0.01	0.9043
Crop diversity	1.58	53.5	2.69	0.1070	-0.18	39.3	0.03	0.8729	0.00	40	0.00	0.9997
Distance market	**0.34**	**55.4**	**4.41**	**0.0403**	-0.13	46.3	0.59	0.4460	0.09	46.2	0.14	0.7103

Covariates chosen based on economic theory and removed in back-wards elimination. Threshold for the deletion model was a significance level of 10%. The model contained a random intercept for each household. Significant effects are bolded. ‡ Parameter estimates for qualitative factors are not shown for brevity.

In table 8, multiple linear regressions are used to account for such covariates. Controlling for these factors, the interaction of mechanization and gender remains highly significant during land preparation. This shows that both mechanization and gender as well as their interaction are strongly correlated with energy requirements. The only other factor that is associated with energy requirements is the distance to markets, which indicates that more isolated farmers work harder. During the weeding period, some additional practices that affect labour requirements are included, especially the use of fertilizer, which may increase time and energy spent on weeding. Another relevant factor is the use of pesticides, in particular herbicides, which may reduce time and energy spent on weeding. Table 6 suggests that the share of energy requirements caused by farming during weeding differs by mechanization type. That is plausible because mechanized ploughing may reduce weed pressure, but when controlling for other factors, the correlation between mechanization of land preparation and energy requirements for weeding becomes insignificant. Land sizes cultivated are significantly and negatively correlated with energy requirements caused by farming, potentially because for households with less land, is may be more essential to engage in weeding to secure a sufficient income. Gender remains a significant factor that is correlated with energy needs. During harvesting and processing, all covariates added in addition to model (1) are insignificant, which suggests that only gender is correlated with the energy requirements that are caused by farming.

To ensure adequate nutrition, differences in energy requirements should be reflected in corresponding differences in caloric intake. As a proxy for caloric intake, portion sizes as reported by respondents were used (see section 2). This made it possible to calculate average daily portion sizes (see table 9). Using perceived portions sizes is confronted with several limitations. One is subjectivity: For example, a person may perceive food portions to be smaller on a day where he or she was working very hard. Another limitation is the assumption that higher portion sizes are associated with more calories regardless of what food is actually eaten. Still, using average daily portion sizes can be seen as a useful proxy that indicates whether caloric energy requirements are likely to be met.

Table 9. Rounded three-day average daily portion sizes and diversity scores

	Manual (1)				*Animal (2)*				*Tractor (3)*				*(1)-(3) (%)*				*(2)-(3) (%)*			
	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G	M	F	B	G
Daily portion sizes																				
Land preparation	1.1	1.2	1.3	1.4	1.4	1.5	1.8	1.4	1.4	1.6	1.5	1.6	20	24	11	13	-5	4	-17	10
Weeding	1	1.1	1.2	1.2	1.3	1.3	1.6	1.4	1.3	1.3	1.6	1.3	22	12	21	12	0	-6	-2	-7
Harvesting/processing	1.3	1.4	1.4	1.6	1.3	1.5	1.4	1.5	1.8	1.9	1.8	1.9	26	28	24	16	27	23	19	22
Daily diversity scores																				
Land preparation	3.2	3.4	3.6	3.6	4.3	4.0	4.4	4.1	4.3	4.3	4.7	4.1	26	19	23	12	2	7	5	0
Weeding	3.1	3.1	3.3	3.3	4.1	4.0	4.0	4.9	4.4	4.1	4.8	4.0	30	24	31	15	7	4	16	-2
Harvesting/processing	3.3	3.6	3.5	3.6	4.2	4.4	4.5	4.7	4.6	5	4.8	4.8	29	29	28	24	9	11	7	2

In table 10, average daily portion sizes were regressed on daily physical activity ratios. In all three seasons, significant differences between the mechanization-specific intercepts were found. During land preparation and weeding, tractor- and animal-households have a significantly higher food intake than manual-households. During harvesting/processing, tractor-households consumed larger average daily portions than both animal- and manual-households. Hence, in spite of the lower energy requirements of tractor- and animal-households, members of these households consume more food than manual-households. During both land preparation and weeding, a significant negative relationship between food intake and energy requirements was found within each mechanization group: people who work harder having have lower levels of food intake. This may be the case because households who need to work less hard are at the same time better off and can, therefore, afford to eat more. Whatever the reasons may be, our findings indicate that people with higher energy requirements who would need more calories due to high hard work generally do not consume more food than households with lower energy requirements. This finding may help to explain the high levels of undernutrition in the Eastern Province of Zambia.

Table 10. Relations between physical activity ratios and average daily portions of food consumed (regression results)

	Land preparation		Weeding		Harvesting/processing	
Effect	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
μ	1.89***	0.24	0.50**	0.20	1.89***	0.08
$c_{.}$	-0.04	0.05	0.08	0.04	-0.05	0.04
π_{Manual}	-0.23**	0.10	-0.15*	0.09	-0.46***	0.09
π_{Animal}	0.05	0.10	0.07	0.09	-0.44***	0.09
γ_{Man}	-0.15	0.10	-0.08	0.08	-0.14	0.09
γ_{Woman}	-0.05	0.10	-0.09	0.07	-0.05	0.09
γ_{Boy}	0.08	0.12	0.11	0.09	-0.10	0.11
$\beta_{daily\ PAR}$	-0.12*	0.12	-0.40*	0.22	0.06	0.09

Parameter estimates with separate intercepts for gender, mechanization and community. The intercepts of community were retained in the model as community was regarded as blocking factor. Gender and mechanization group specific slopes were not significant.

5 Discussion

Understanding agriculture-nutrition linkages can help to target policy interventions that improve the nutrition of smallholder farmers. So far, these linkages have been studied focusing mostly on the nutritional effects of farm yields and farm diversity. In this paper, the focus was placed on an agriculture-nutrition linkage that has been rather neglected in the recent literature: the link between farm technologies and caloric energy requirements and, consequently, nutritional outcomes. The paper aimed to assess to which extent such linkages are of relevance to explain differences in nutritional outcomes. To do so, the relation between agricultural mechanization and caloric energy requirements was explored. The results suggest that this agricultural-nutrition link is indeed of high relevance for understanding the nutritional status of smallholder farmers. During all farming steps analysed, the daily energy requirements arising from farming activities were found to be high, which confirms the literature that highlights the high caloric energy needs of smallholder farmers (Dufour & Piperata, 2008; Zanello et al., 2017). For example, depending on the farm step (land preparation, weeding, harvesting/processing), between 3000 and 3800 calories are needed per day for adult men, which exceeds the often stated average of 2800 calories per day needed by males, but reflects an early FAO report arguing that heavy working adult men need up to 4400 calories per day (FAO, 1957). Such high levels may affect the total time that people are able to devote to farming: farmers may work less than would be optimal because they do not have sufficient dietary energy to do so. Overall daily energy requirements were found to be largely determined by the energy required for farming. During land preparation, for example, farming was responsible for up to 44 % of the daily energy need for men and 29% for women. Additional areas requiring much energy are transportation activities, many of which are related to farming, and domestic chores, particularly for women.

The results show that agricultural mechanization for land preparation is negatively associated with daily energy requirements, for subsequent farm steps, the results are mixed. Male and female adults in households using tractors for land preparation have 17% to 20% lower energy requirements than households using manual labour. On the average, this translates to 533 and 483 calories needed less per day for male and female adults, respectively, when tractors are used. In general, individuals in non-mechanized households have higher energy requirements, but consume less food and may thus at least seasonally suffer from undernutrition, especially during the heart of the farming season, which corresponds with the hunger months when last year's harvest dwindles and this year's harvest is not yet ready (see also Mukuka & Mofu, 2016). Crucially, even in households with mechanized land preparation, energy requirements seem to remain high and exceed the FAO recommendation of 2800 calories per day for adult men and 2000 calories per adult women. This suggests that, for the Zambian case analysed here, increasing obesity levels due to the reduction of caloric energy requirements without corresponding diet changes are still unlikely, at least in the near future. However, the data used for this paper was collected during peak seasons, and energy requirements may be lower during the lean season. The link between agricultural mechanization, physical activities and obesity should therefore be carefully monitored, especially given findings from other studies which show that smallholder farming households are not exempt from the double burden of malnutrition (Jones-Smith et al., 2012; Roemling and Qaim, 2012).

Our findings suggest that paying more attention to this forgotten agriculture-nutrition linkage may help to design policies and programs to reduce the prevalence of undernutrition among smallholder farmers as well as increase their labour productivity. While the study was able to highlight the relevance of this link, the link was also found to be highly complex. Substitution effects were found to play a large role. In households using animal draft power, the daily energy requirements related to farming were found to be significantly lower as compared to households using manual labour, but the overall physical activity levels are still similar - especially for adult males who use the time "saved" due to mechanization to pursue other energy-intensive tasks, such as transportation. The study shows that gender plays a large role, as well. In general, men tend to have higher energy needs than women during the key farming steps observed, which confirms findings from Zanello et al. (2017) in Ghana. The findings suggest that studies examining gender roles and power relations in farming households should look beyond the allocation of time-use and consider different activity levels, as well. Similarly, the effects of time use and energy requirements on children should be considered, as well. The findings of this study show that during the weeding period, when, regardless of mechanization level, many children leave their schools to work on the fields, they have daily shares of energy requirements related to farming that are similar to those of adults.

Given this complexity, this study should be considered as explorative. Various open questions remain and the study encourages future research to address them. Our study underlines that collection of data on time use, physical activity, nutritional requirements as well as anthropometric measures is needed at the individual level (rather than the household level) across the entire farming season. Our study also suggests that collecting detailed time-use data as well as nutritional data by individuals themselves using a smartphone app and then converting such data into energy requirements may be a promising way to do so, notwithstanding some limitations. The utilization of time-use data and metabolic equivalent tasks (MET) provides an estimate of energy requirements, but such an approach cannot consider efficiency of movement and intensity of efforts. Moreover, this approach does not consider environmental conditions such as temperature (Consolazio, 1969; Durnin, 1967; Ocobock, 2016). Despite such shortcomings, van der Ploeg et al. (2010) found that energy requirements calculated using time-use data and METs closely resemble the energy requirements measured with accelerometers. Still, more research is needed to validate this approach, for example, by using accelerometer devices (Limb et al., 2019). Zanello et al. (2017) have shown that combining data from accelerometer devices with time-use data can lead to rich data. However, more attention needs to be paid to validate the accuracy of accelerometers for farm and rural tasks (see also Prista et al. ,2009).

Another limitation of this study is the fact that we only collected rather limited data on nutrition quality. Future studies focusing on time-use, physical activity and energy demands would benefit from simultaneously collecting high-quality data on nutrition quality. Combining the Timetracker app with applications developed for collecting nutritional data like may be a way forward. An example is the Calculator of Inadequate Micronutrient Intake (CIMI), an app that makes it possible to record food items consumed by a household and to assess the levels of energy, protein and micronutrients absorbed (Wald et al., 2017). Data collection for CIMI relies, so far, on enumerators using tablets, but following the Timetracker approach, it seems feasible that individual household members record this information themselves using a smartphone app. This approach would make it possible to study the link between farm technologies and nutritional quality requirements in more detail. The question of nutritional quality (i.e. going beyond dietary energy requirements) may be important when studying the impact of mechanization on nutrition, because physical activity can influence the absorption of and increase the need for some micronutrients (Manore, 2000).

6 Conclusion and Policy Implications

Our findings show that agricultural research and policy efforts on agricultural development such as input subsidy programs but also nutritional programs, should, in addition to other agricultural-nutrition linkages, include the linkage between farm technologies and nutritional outcomes. Such efforts should consider energy requirements as well as other nutritional requirements caused by farm-related physical activity. Such an approach could help to better understand which agricultural growth pathways contribute most to positive nutritional outcomes, especially for members of rural households who are vulnerable to undernutrition or other forms of malnutrition.

Promoting agricultural mechanization that saves human energy, including farm mechanization (using tractors rather than draught animals) and post-harvest processing equipment, seems to be a promising pathway to contribute to reducing undernutrition in smallholder farm households, at least in situations that are comparable to the Zambian case study conditions. However, it is important to keep in mind that mechanization may affect nutrition through additional pathways that are not yet explored, for example, through changes in the types of crops that are grown or by making time available for horticulture and kitchen gardens. Beyond farm mechanization, rural mechanization may offer other opportunities to reduce malnutrition, e.g., by mechanizing transportation and domestic activities, which were also found to have a large influence on daily energy requirements.

The risk of obesity arising from mechanization was not observed in our case study, probably because, as indicated by high rates of malnutrition, deficiency of dietary energy is still a major problem, and because households do various other activities associated with high physical activity levels such as transportation. However, there is a need to carefully monitor the potential impact of mechanization and other caloric energy saving technologies on obesity, considering that raising obesity levels have been observed in rural areas of various developing countries (Jones-Smith et al., 2012; Roemling and Qaim, 2012). In such a case, accompanying policies such as leisure time exercise would be needed. Overall, we hope that this case study encourages researchers and practitioners to rediscover the forgotten link between mechanization and nutrition and to use novel approaches study this link in all its complexity.

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8 Appendix

Activities	PAR	Ainsworth Compendium Code (AC) / FAO Label - Comments
Farming and related activities		
Land Clearing Manual	6,30	AC08030 "clearing land, … , vigorous effort"
Land Clearing Animal	4,80	FAO "ploughing with horse"
Land Clearing Mechanical	2,80	AC11170 "farming, driving tasks (e.g., driving tractor)"
Hoeing Manual	5,00	AC08241 "… using hoe, moderate-to-vigorous effort"
Ploughing Animal	4,80	FAO "ploughing with horse"
Ploughing Mechanical	2,80	AC11170 "farming, driving tasks (e.g., driving tractor)"
Harrowing Animal	3,84	FAO "ploughing with horse" - 20
Harrowing Mechanical	2,80	AC11170 "farming, driving tasks (e.g., driving tractor)"
Potholing Manual	5,00	AC08050 "digging, spading, filling garden, … "
Ripping Animal	3,84	FAO "ploughing with horse" - 20
Ripping Mechanical	2,80	AC11170 "farming, driving tasks (e.g., driving tractor)"
Ridging Manual	7,80	AC08052 "... ridging, vigorous effort"
Ridging Animal	4,80	FAO "ploughing with horse"
Ridging Mechanical	2,80	AC11170 "farming, driving tasks (e.g., driving tractor)"
Raking Manual	3,80	AC08160 "raking lawn or leaves, moderate effort"
Planting Manual	4,30	AC08145 "planting crops, …, moderate effort"
Planting Mechanical	2,80	AC11170 "farming, driving tasks (e.g., driving tractor)"
Dibbling Manual	3,80	AC08145 "planting crops, …, moderate effort"
Fertilization Manual	3,00	AC 08220 "walking, applying fertilizer or seeding … "
Fertilization Mechanical	2,80	AC11170 "farming, driving tasks (e.g., driving tractor)"
Fertilization Manual Manure	4,80	AC11146 ("...spreading manure… ")
Weeding Manual	5,00	AC08241 "weeding,..., hoe moderate-to-vigorous effort"
Weeding Animal	4,80	FAO "ploughing with horse"
Weeding Knapsack	4,30	FAO "spraying crops"
Guarding of Crops (Manual)	2,50	AC17085 "bird watching, slow walk"
Irrigation Manual Watering	2,50	AC05148 "watering plants"
Harvesting Manual	4,80	AC11146 "farming, moderate effort e.g., ... harvesting"
Bundling Manual	3,70	FAO "bundling rice"
Drying Manual	1,90	FAO "sorting"
Storing Manual	9,65	FAO "loading 16 kg sack on to a truck"
Bagging Manual	3,90	FAO "bagging and splitting"
Shelling Manual	2,00	AC05050 "…. cooking, de-shelling groundnuts"
Shelling Mechanical	3,80	AC11195 "… grain milling activities"
Manual Grinding/Pounding/Milling	5,60	FAO "pounding grain"
Mech. Grinding/Pounding/Milling	3,80	AC11195 "… grain milling activities"
Winnowing Manual	2,80	Ø Male and Female FAO "winnowing"
Beverage Preparation	2,90	FAO "brewery work"
Marketing	1,50	AC11580 "sitting tasks, light effort … "
Animal Husbandry	4,80	AC11146 "…. feeding animals, chasing cattle ..."
Hunting	5,00	AC04100 "hunting, general"
Fishing	3,50	AC04001 "fishing, general"
Gathering	3,50	AC08246 "…picking fruits/vegetables, moderate effort"
Charcoal Making	6,30	AC11110 "coal mining, shoveling coal"
Maintaining Repairing	3,50	Ø AC06127 "home repair… moderate effort" and AC06126 "…light effort"
Farm Administration	1,50	AC11580 "sitting tasks, light effort (e.g., office work)"
Vegetable Garden	3,50	AC08245 "gardening, general, moderate effort"
Cooking Community	2,00	AC05050 "cooking or food preparation ... light effort "
Construction Community	4,00	AC11120 "construction, outside, ..."
Meeting	1,50	AC11585 "sitting meetings ..."
Construction Household	4,00	AC11120 "construction, outside, ..."
Off farm work	2,30	AC11003 "active workstation, treadmill desk, walking"
Transportation		
Walking Loaded	5,00	AC11820 "… carrying objects about 25 to 49 pounds"
Walking Unloaded	3,50	AC17190 "walking, 2.8 to 3.2mph, level, moderate pace, firm surface"
Motorbike Loaded	3,08	AC16030 "motor scooter, motorcycle" + 10
Motorbike Unloaded	2,80	AC16030 "motor scooter, motorcycle"
Bicycle Loaded	9,60	AC01030 "bicycling, 12-13.9 mph, leisure, moderate effort" + 20
Bicycle Unloaded	8,00	AC01030 "bicycling, 12-13.9 mph, leisure, moderate effort"
Animal Cart Loaded	2,50	AC16010 "automobile or light truck (not a semi) driving"
Animal Cart Unloaded	2,50	AC16010 "automobile or light truck (not a semi) driving"
Car Van Loaded	1,90	Ø AC16010 "automobile or light truck … driving" and AC16015 "riding in a car or truck"
Car Van Unloaded	1,90	Ø AC16010 "automobile or light truck … driving") and AC16015 "riding in a car or truck"
Bus Loaded	1,30	AC16016 "riding in a bus or train"
Bus Unloaded	1,30	AC16016 "riding in a bus or train"
Tractor Loaded	2,80	AC08055 "driving tractor"
Tractor Unloaded	2,80	AC08055 "driving tractor"
Education	1,80	AC09065 "sitting, in class, general, including note-taking or class discussion"
Care		
Care of children	2,50	AC05184 "child care, infant, general"
Care of sick	3,15	Ø AC05200 "elder care ... " and AC05205 "elder care … light effort, ..."
Care of old	3,15	Ø AC05200 "elder care ... " and AC05205 "elder care … light effort, ..."
Household Chores		
Catching water	5,00	AC11820 "… carrying objects about 25 to 49 pounds"
Collecting firewood	3,30	AC08009 "carrying, …. , light-to-moderate effort"
Cooking	2,00	AC05050 "cooking or food preparation ... light effort ")
Cleaning	3,30	AC05010 "cleaning, sweeping carpet or floors, general")
Washing pots	2,50	AC05042 "wash dishes, clearing dishes from table, walking, light effort"
Washing clothes	4,00	AC05092 "laundry, hanging wash, washing clothes by hand, moderate effort"
Buying groceries	2,30	AC05060 "food shopping … , standing or walking"
Personal Care		
Sleeping	0,95	AC07030 "sleeping"
Resting	1,30	AC07021 "sitting quietly, general"
Being Sick	1,50	AC13036 "taking medication, sitting or standing"
Eating Drinking	1,50	AC13030 "eating, sitting"
Personal Hygiene	2,00	AC13050 "showering, toweling off, standing"
Social Life		
Media	1,50	AC07025 "listening to music... movie" or AC09055 "phone … text messaging, light effort"
Religion	2,00	AC20020 "standing, singing in church, attending a ceremony, standing, active participation"
Chatting	1,30	AC07060 "reclining, talking or talking on phone"
Sports	7,00	AC15610 "soccer, casual, general"
Dancing/Music/Socializing	3,15	Ø AC03025 "cultural dancing" and AC09100 "retreat … incl. sitting, relaxing, talking, eating"

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