# Supplementary Material

## S1. AGRICULTURAL SYSTEM MODEL

### S1.1) Estimation of household food consumption

Annual food consumption was quantified for each food item *i* using official statistics for the rural area of Cusco corresponding to 2023 and 2024, selecting products with a coefficient of variation less than 15% and using the average of both years as a dietary reference [1]. This diet was validated with residents to verify its plausibility in the community context.

$$FC_i = \frac{FC_{i,2023} + FC_{i,2024}}{2}$$

Where:

- $FC_i$ = average annual consumption of food item $\boldsymbol{i}$ (kg·person$^{-1}$·year$^{-1}$)
- $FC_{i,2023,2024}$ = reported consumption during each reference year.

Community-level food demand was obtained by scaling individual consumption to the total population:

$$CF_i = \frac{FC_i \times P}{1000}$$

Where:

- $CF_i$ = community consumption of food item *i* (t·year$^{-1}$)
- $FC_i$ = average annual consumption of food item *i* (kg·person$^{-1}$·year$^{-1}$)
- P = population of the community (171 inhabitants) (data from survey).
- 1000 = conversion factor from kg to tonnes.

### S1.2) Nutritional flow accounting

Each food item was linked to an equivalent item in the Peruvian Food Composition Tables to assign nutritional conversion factors for energy and macronutrients [2], while for Suillus luteus, specific coefficients reported in [3] were used. The daily energy contribution was calculated as:

$$ET_i = \frac{FC_i \times 1000 \times ECF_i}{365}$$

Where:

- $ET_i$ = dietary energy supplied by food *i* (kcal·person$^{-1}$·day$^{-1}$)
- $FC_i$ = average annual consumption of food item *i* (kg·person$^{-1}$·year$^{-1}$)
- $ECF_i$ = energy conversion factor for food item *i* (kcal·g$^{-1}$).
- 1000 = conversion factor from kg to g.
- 365 = conversion factor from years to days.

The protein intake was calculated as:

$$PR_i = \frac{FC_i \times 1000 \times pcf_i}{365}$$

Where:

- $PR_i$ = protein intake from food item *i* (g·person$^{-1}$·day$^{-1}$)
- $FC_i$ = average annual consumption of food item *i* (kg·person$^{-1}$·year$^{-1}$)
- $pcf_i$ = protein conversion factor for food item *i* (g protein·g$^{-1}$ food).
- 1000 = conversion factor from kg to g.
- 365 = conversion factor from years to days.

Similarly, fat and carbohydrate flows were obtained:

$$F_i = \frac{FC_i \times 1000 \times f_i}{365}$$

Where:

- $F_i$ = fat intake from food item *i* (g·person$^{-1}$·day$^{-1}$)
- $FC_i$ = average annual consumption of food item *i* (kg·person$^{-1}$·year$^{-1}$)
- $f_i$ = fat conversion factor for food item *i* (g fat·g$^{-1}$ food).
- 1000 = conversion factor from kg to g.
- 365 = conversion factor from years to days.

$$CH_i = \frac{FC_i \times 1000 \times ch_i}{365}$$

Where:

- $CH_i$ = carbohydrate intake from food item *i* (g·person$^{-1}$·day$^{-1}$)
- $FC_i$ = average annual consumption of food item *i* (kg·person$^{-1}$·year$^{-1}$)
- $ch_i$ = carbohydrate conversion factor for food item *i* (g carbohydrate·g$^{-1}$ food).
- 1000 = conversion factor from kg to g.
- 365 = conversion factor from years to days.

The energetic contribution of protein and fat were calculated using the conversion factors obtained from [4]:

$$E_{protein,i} = PR_i \times \alpha_p$$

Where:

- $E_{protein,i}$ = dietary energy contribution from proteins for food item *i* (kcal·person$^{-1}$·day$^{-1}$).
- $PR_i$ = protein intake from food item *i* (g·person$^{-1}$·day$^{-1}$)
- $\alpha_p$ = protein energy coefficient (kcal·g$^{-1}$)

$$E_{fat,i} = F_i \times \alpha_f$$

Where:

- $E_{fat,i}$ = dietary energy contribution from fats for food item *i* (kcal·person$^{-1}$·day$^{-1}$).
- $F_i$ = fat intake from food item *i* (g·person$^{-1}$·day$^{-1}$)
- $\alpha_f$ = fat energy coefficient (kcal·g$^{-1}$)

The energetic contribution attributed to carbohydrates was estimated by difference using the dietary energy balance approach.

$$E_{carb,i} = ET_i - (E_{protein,i} + E_{fat,i})$$

Where:

- $E_{carb,i}$ = dietary energy contribution from carbohydrate for food item *i* (kcal·person$^{-1}$·day$^{-1}$).
- $ET_i$ = dietary energy supplied by food *i* (kcal·person$^{-1}$·day$^{-1}$)
- $E_{protein,i}$ = dietary energy contribution from proteins for food item *i* (kcal·person$^{-1}$·day$^{-1}$).
- $E_{fat,i}$ = dietary energy contribution from fats for food item *i* (kcal·person$^{-1}$·day$^{-1}$).

This step allowed the comparison between dietary composition and the metabolic requirements supported by the production system.

**S1.3)** Conversion from consumed food to primary agricultural equivalent

Because several consumed products correspond to processed commodities, food flows were converted into their primary agricultural equivalents. The conversion factors were obtained from [5]. For each product:

$$UFE_i = \frac{FC_i}{\gamma_i}$$

Where:

- $UFE_i$ = unprocessed food equivalent for item *i* (kg·person$^{-1}$·year$^{-1}$).
- $FC_i$ = average annual consumption of food item *i* (kg·person$^{-1}$·year$^{-1}$)
- $\gamma_i$ = processed-to-unprocessed conversion factor.

For unprocessed foods, $\gamma_i = 1$; therefore:

$$UFE_i = FC_i$$

The community-level demand expressed as a primary equivalent was calculated as:

$$CUFE_i = \frac{UFE_i \times P}{1000}$$

Where:

- $CUFE_i$ = community demand for primary agricultural product *i* (t·year$^{-1}$).
- $UFE_i$ = unprocessed food equivalent for item *i* (kg·person$^{-1}$·year$^{-1}$).
- P = population of the community (171 inhabitants) (data from survey).
- 1000 = conversion factor from kg to tonnes.

This transformation ensures consistency between the consumption compartment and the agricultural production compartment.

**S1.4)** Land requirement

The land fund required to sustain food consumption was calculated by linking primary food demand with agricultural productivity. For local food, reference values adjusted and validated with local farmers were used. For imported food, national yields were used, except for wheat, for which Canada's yield was used because this country is the main source of wheat consumed in Peru. Most yields were obtained from [6] and, when specific records were unavailable, from [7]. For each crop ***i***:

$$LU_i = \frac{CUFE_i}{Y_i}$$

Where:

- $LU_i$ = land requirement for crop $i$ (ha·year$^{-1}$).
- $CUFE_i$ = community demand for primary agricultural product $i$ (t·year$^{-1}$).
- $Y_i$ = crop yield for crop $i$ (t·ha$^{-1}$).

The total land requirement was calculated as:

$$LU_{total} = \sum LU_i$$

Land requirements were classified according to the origin of the food flow:

$$LU_{total} = LU_{local} + LU_{external}$$

Where:

- $LU_{total}$ = total land requirement (ha·year$^{-1}$).
- $LU_{local}$ = land embodied within the community boundary (ha·year$^{-1}$).
- $LU_{external}$ = land appropriated outside the local socio-ecological system through food imports (ha·year$^{-1}$).

**S1.5)** Human activity requirement

The human activity required for food production was estimated using crop-specific labor coefficients. In this case, data were obtained from the production cost records of the Peruvian Ministry of Agrarian Development and Irrigation (MIDAGRI). These local values were subsequently validated through consultations with farmers within the community. Labor expressed in person-days was converted into hours:

$$LC_i = PD_i \times 8$$

Where:

- $LC_i$ = labor coefficient for crop $i$ (h·ha$^{-1}$).
- $PD_i$ = agricultural labor demand for crop $i$ (person-days·ha$^{-1}$).
- 8 = conversion factor from working days to hours (h·day$^{-1}$).

The total labor requirement per crop was calculated as:

$$HA_i = LU_i \times LC_i$$

Where:

- $HA_i$ = human activity allocated to the production of crop $i$ (h·year$^{-1}$).
- $LU_i$ = land requirement for crop $i$ (ha·year$^{-1}$).

The total human activity requirement for food production was obtained as follows:

$$HA_{food} = \sum HA_i$$

Where:

- $HA_{food}$ = total human activity requirement (h·year$^{-1}$).

This represents the allocation of the Human Activity fund required within the agricultural compartment to reproduce the observed food consumption pattern.

**S1.6)** Green and blue water requirement

Water appropriation associated with food consumption was quantified using crop-specific water footprint coefficients [8]. Because crop-specific water data were not available for Patapallpa Alta, data for Cusco were used as a proxy. The green water and blue water requirements for each food item ***i*** are calculated as follows:

Green water requirement:

$$GW_i = CF_i \times gw_i$$

Where:

- $GW_i$ = green water requirement ($m^3 \cdot year^{-1}$).
- CFi = community consumption of food item i (t·year-1)
- $gw_i$ = green water coefficient ($m^3 \cdot t^{-1}$).

Blue water requirement:

$$BW_i = CF_i \times bw_i$$

Where:

- $BW_i$ = blue water requirement ($m^3 \cdot year^{-1}$).
- $CF_i$ = community consumption of food item i (t·year-1)
- $bw_i$ = blue water coefficient ($m^3 \cdot t^{-1}$).

Total water appropriation was:

$$GW_{total} = \sum GW_i$$

$$BW_{total} = \sum BW_i$$

and was separated according to production origin:

$$GW_{total} = GW_{local} + GW_{external}$$

$$BW_{total} = BW_{local} + BW_{external}$$

## S2) LIVESTOCK SYSTEM MODEL

### S2.1) Conversion of animal food demand into livestock production requirements

The starting point was the annual community demand for each animal product ***j***

$$D_j$$

Where:

- $D_j$ = annual community demand of animal product ***j*** (t·year$^{-1}$).

Data obtained from the household food consumption model.

S2.1.1) Meat production systems

For meat products, the demand for edible meat was converted into the required live animal biomass using a meat-to-live weight yield coefficient:

$$LW_j = \frac{D_j}{\theta_j}$$

Where:

- $LW_j$ = is the live weight equivalent required for animal *j* (t live weight·year$^{-1}$).
- $D_j$ = is the edible meat demand for animal product *j* (t meat·year$^{-1}$).
- $\theta_j$ = is the meat-to-live weight yield coefficient for animal *j* (t meat·t live weight$^{-1}$).
- *j* = denotes the specific livestock or animal product category (e.g., bovine, ovine, poultry).

The number of slaughtered animals required annually was calculated as follows:

$$N_{sl,j} = \frac{LW_j}{W_j}$$

Where:

- $LW_j$ = is the live weight equivalent required for animal j (t live weight·year-1).
- $N_{sl,j}$ = is the number of slaughtered animals required per year for livestock j (animals·year-1).
- $W_j$ = is the average live weight at slaughter for animal j (t·animal-1).
- *j* = denotes the livestock category.

a) *Chicken meat model:*

$$N_{chicken} = \frac{LW_{chicken}}{W_{chicken}}$$

Where:

- $N_{chicken}$ = required number of broiler chickens (birds·year$^{-1}$).
- $LW_{chicken}$ = live weight equivalent required for chicken meat production (t live weight·year$^{-1}$)
- $W_{chicken}$ = average live weight at slaughter per broiler chicken (t live weight·bird$^{-1}$)

Mortality losses during production were incorporated:

$$N_{start} = \frac{N_{chicken}}{1 - M}$$

Where:

- $N_{start}$ = initial number of birds required at the beginning of the production cycle (birds·year$^{-1}$).
- $N_{chicken}$ = required number of broiler chickens (birds·year$^{-1}$).
- M = mortality rate during the production cycle (dimensionless).

The total chicken population represents the animal fund required to maintain the observed chicken meat consumption.

*b) Egg production system*

Egg demand was converted into the required laying-hen population according to annual egg productivity:

$$N_{hen} = \frac{D_{egg}}{Y_{egg}}$$

Where:

- $N_{hen}$ = required number of laying hens (hens)
- $D_{egg}$ = annual egg demand (t egg·year$^{-1}$)
- $Y_{egg}$ = annual egg yield per hen (t egg·hen$^{-1}$·year$^{-1}$)

Considering mortality:

$$N_{start,hen} = \frac{N_{hen}}{1 - M_{hen}}$$

Where:

- $N_{start}$ = initial number of laying hens required (hens)
- $N_{hen}$ = productive laying-hen population required after mortality losses (hens)
- $M_{hen}$ = mortality rate during the production period (dimensionless).

*c) Sheep meat production system:*

$$N_{sheep} = \frac{LW_{sheep}}{W_{sheep}}$$

Where:

- $N_{sheep}$ = number of sheep required for slaughter (sheep·year$^{-1}$).
- $LW_{sheep}$ = live weight equivalent required for sheep meat production (t live weight·year$^{-1}$)
- $W_{sheep}$ = average live weight at slaughter per sheep (t live weight·sheep$^{-1}$)

For sheep, the required slaughter rate was connected to the standing flock using the annual offtake rate:

$$F_{sheep} = \frac{N_{sl,sheep}}{OR}$$

Where:

- $F_{sheep}$ = average annual flock size (animals).

- $N_{sl.sheep}$ = number of sheep slaughtered annually (sheep·year$^{-1}$)
- OR = annual offtake rate (sheep slaughtered·sheep$^{-1}$·year$^{-1}$)

The internal flock structure was then distributed according to demographic coefficients:

$$F_k = F_{sheep} \times S_k$$

Where:

- $F_k$ = number of animals in class $k$.
- $F_{sheep}$ = average annual flock size (animals).
- $S_k$ = proportion of each flock category.

Classes considered were:

- Ewes.
- Yearling ewes.
- Yearling rams.
- Rams.
- Female lambs.
- Male lambs.

Birth dynamics were represented as:

$$B = E \times BR$$

Where:

- B = annual lamb births (lambs·year$^{-1}$)
- E = reproductive females (Ewes)
- BR = gross birth rate.

Surviving lamb production:

$$L = B \times SR$$

Where:

- L = annual surviving lamb production (lambs·year$^{-1}$)
- B = annual lamb births (lambs·year$^{-1}$)
- SR = Lamb survival rate.

This links the population fund with the annual meat flow.

**S2.2)** <u>Animal feed requirements</u>

S2.2.1) Concentrate-fed systems

*a) chicken meat and eggs*

Total feed requirement was calculated from animal productivity coefficients:

*b) For broiler chickens:*

$$Feed_{broiler} = N_{start} \times FI$$

Where:

- $Feed_{broiler}$ = total feed requirement for broiler chicken production (t feed.year$^{-1}$)
- $N_{start}$ = initial number of birds required for production (birds.year$^{-1}$)
- FI = feed intake per bird (t feed.bird$^{-1}$).

*c) For eggs:*

$$Feed_{egg} = D_{egg} \times FCR$$

Where:

- $Feed_{egg}$ = total feed requirement for egg production (t dry matter feed·year$^{-1}$)
- $D_{egg}$ = annual egg production demand (t egg·year$^{-1}$)
- FCR = feed conversion ratio (t dry matter feed·t$^{-1}$ egg)

Feed was disaggregated according to ration composition:

$$Feed_{i,p} = Feed_p \times R_{i,p}$$

Where:

- $Feed_{i,p}$ = demand of ingredient $i$ for production system $p$ (t dry matter ingredient·year$^{-1}$)
- $p$ = broiler or egg
- $Feed_p$ = total feed requirement for production system $p$, where $p$ is broiler or egg (t dry matter feed·year$^{-1}$)
- $R_{i,p}$ = proportion of ingredient $i$ in the ration of production system $p$

In this case, only agricultural ingredients were incorporated into land and water accounting:

- Maize.
- Soybean meal.
- Palm oil.

S2.2.2) Conversion from processed feed ingredients to primary biomass

Feed ingredients were corrected for moisture content:

$$FW_i = \frac{Feed_i}{1 - MC_i}$$

Where:

- $FW_i$ = fresh weight equivalent of feed ingredient $i$ (t fresh matter feed·year$^{-1}$).
- $Feed_i$ = feed ingredient demand for ingredient $i$ (t dry matter ingredient·year$^{-1}$)
- $MC_i$ = moisture content of ingredient $i$(dimensionless)

Processed ingredients were transformed into primary crop equivalents:

$$PE_i = \frac{FW_i}{\gamma_i}$$

Where:

- $PE_i$ = primary crop equivalent of feed ingredient *i* (t fresh primary biomass·year$^{-1}$).
- $FW_i$ = fresh weight equivalent of feed ingredient *i* (t fresh matter feed·year$^{-1}$).
- $\gamma_i$ = processed-to-unprocessed conversion factor for ingredient *i*(dimensionless).

S2.2.3) Grazing and forage-based livestock systems

For sheep and cattle, forage requirements were calculated from animal biomass requirements.

Daily forage consumption:

$$FI = LW \times r$$

Where:

- FI = daily forage intake per animal (kg dry matter·animal$^{-1}$·day$^{-1}$)
- LW = animal live weight (kg animal$^{-1}$)
- r = daily forage intake (% live weight).

Annual forage demand:

$$AF = FI \times 365 \times N$$

Where:

- AF = annual forage requirement (kg dry matter·year$^{-1}$).
- FI = daily forage intake per animal (kg dry matter·animal$^{-1}$·day$^{-1}$)
- N = number of animals (animals).
- 365 = number of days per year.

S2.2.4) Milk production model

Milk demand was converted into dairy cattle requirements.

The annual milk productivity per cow was:

$$MY = MP_d \times LD$$

Where:

- MY = annual milk yield per cow (L milk·cow$^{-1}$·year$^{-1}$)
- $MP_d$ = daily milk production per cow (L milk·cow$^{-1}$·day$^{-1}$).
- LD = lactation duration (days·year$^{-1}$).

Required dairy herd:

$$N_{cow} = \frac{D_{milk}}{MY}$$

Where:

- $N_{cow}$ = required number of dairy cows (cows)
- $D_{milk}$ = annual milk demand (L milk·year$^{-1}$)
- MY = annual milk yield per cow (L milk·cow$^{-1}$·year$^{-1}$)

Feed demand:

$$FD = N_{cow} \times DMI \times LD$$

Where:

- FD = total annual dry matter feed requirement (kg dry matter·year$^{-1}$).
- $N_{cow}$ = required number of dairy cows (cows)
- DMI = daily dry matter intake per cow (kg dry matter·cow$^{-1}$·day$^{-1}$).
- LD = lactation duration (days·year$^{-1}$)

Feed allocation

$$FD_i = FD \times C_i$$

Where:

- $FD_i$ = annual dry matter requirement of feed component *i* (kg dry matter·year$^{-1}$).
- FD = total annual dry matter feed requirement (kg dry matter·year$^{-1}$).
- $C_i$ = share of feed component *i* in the diet (dimensionless).

Components:

- grazed pasture
- ryegrass-clover cut forage.

**S2.3)** Land requirement

Animal feed demand was translated into land requirements:

$$LU_i = \frac{PE_i}{Y_i}$$

Where:

- $LU_i$ = land requirement for feed component *i* (ha·year$^{-1}$).
- $PE_i$ = primary crop equivalent of feed ingredient *i* (t fresh primary biomass·year$^{-1}$).
- $Y_i$ = yield of feed component *i* (t·ha$^{-1}$)

Total livestock-associated land:

$$LU_{animal} = \sum LU_i$$

- $LU_{animal}$ = land requirement for feed component *i* (ha·year$^{-1}$).

For sheep, the land requirement:

$$LU_{grazing} = \frac{F_{sheep}}{ST}$$

Where:

- $LU_{grazing}$ = grazing land requirement (ha·year$^{-1}$).
- $F_{sheep}$ = annual average flock size.
- ST = stocking rate (sheep·ha$^{-1}$)

The model distinguishes:

$$LU_{animal} = LU_{local} + LU_{external}$$

Where:

- local land = pasture and locally produced feed
- external land = imported feed embodied land.

**S2.4)** Human activity requirement

Animal husbandry labor:

$$HA_{animal} = N \times LC_a$$

Where:

- $HA_{animal}$ = human activity used to animal management (h·year$^{-1}$)
- N = number of animals required (animals)
- $LC_a$ = labor coefficient per animal (h·animal$^{-1}$·year$^{-1}$).

Crop/feed production labor:

$$HA_{feed} = \sum_i (LU_i \times LC_i)$$

Where:

- $HA_{feed}$ = total human activity allocated to animal feed production (h·year$^{-1}$).
- $LU_i$ = land requirement for feed component *i* (ha·year$^{-1}$).
- $LC_i$ = labor coefficient for feed component *i* (h·ha$^{-1}$).

Total livestock labor:

$$HA_{livestock} = HA_{animal} + HA_{feed}$$

**S2.5)** Water accounting

*a) Feed-related water:*

Green water:

$$GW_i = PE_i \times gw_i$$

Where:

- $GW_i$ = green water requirement (m$^3$·year$^{-1}$).
- $PE_i$ = primary crop equivalent (t·year$^{-1}$).
- $gw_i$ = green water coefficient (m$^3$·t$^{-1}$).

Blue water:

$$BW_i = PE_i \times bw_i$$

Where:

- $BW_i$ = blue water requirement (m$^3$·year$^{-1}$).
- $PE_i$ = primary crop equivalent (t·year$^{-1}$).
- $bw_i$ = blue water coefficient (m$^3$·t$^{-1}$).

*b) Direct livestock water*

Animal drinking water:

$$DW_j = N_j \times d_j \times 365$$

Where:

- $DW_j$ = annual drinking water requirement for animal type *j* ($m^3 \cdot year^{-1}$).
- $N_j$ = number of animals of type *j* (animals),
- $d_j$ = daily drinking water requirement per animal ($m^3 \cdot animal^{-1} \cdot day^{-1}$).
- 365 = number of days per year

c) *Service water:*

$$SW_j = N_j \times s_j \times 365$$

Where:

- $SW_j$ = annual service water requirement for animal type *j* ($m^3 \cdot year^{-1}$).
- $N_j$ = number of animals of type *j* (animals),
- $s_j$ = daily service water requirement per animal ($m^3 \cdot animal^{-1} \cdot day^{-1}$).
- 365 = number of days per year

d) *Total blue water:*

$$BW_{animal} = \sum_i BW_{feed,i} + \sum_j DW_j + \sum_j SW_j$$

**S2.6)** Guinea pig production model

The metabolic size of the subsystem was defined by the total annual animal output:

$$O_{total} = O_{market} + O_{food}$$

Where:

- $O_{total}$ = total annual guinea pig output ($animal \cdot year^{-1}$).
- $O_{market}$ = guinea pigs sold outside the community system ($animals \cdot year^{-1}$).
- $O_{food}$ = guinea pigs consumed locally ($animals \cdot year^{-1}$).

S2.6.1) Estimation of market-oriented production

Market production was estimated from household production information obtained through community surveys.

Annual animal sales were calculated as:

$$O_{market} = S_m \times 12 \times H$$

Where:

- $O_{market}$ = guinea pigs sold outside the community system ($animals \cdot year^{-1}$).
- $S_m$ = average monthly guinea pig sales per producing household ($animals \cdot household^{-1} \cdot month^{-1}$).
- H = number of households involved in guinea pig production.
- 12 = conversion factor from months to years ($months \cdot year^{-1}$).

This represents the monetary-output component of the livestock subsystem.

S2.6.2) Conversion of local meat consumption into animal requirements

Community guinea pig meat demand was converted into live animal biomass using the carcass conversion coefficient:

$$LW_{gp} = \frac{M_{gp}}{\theta_{gp}}$$

Where:

- $LW_{gp}$ = required guinea pig live weight production (t live weight· year$^{-1}$)
- $M_{gp}$ = guinea pig meat consumed by the community (t meat· year$^{-1}$).
- $\theta_{gp}$ = carcass yield coefficient (t meat·t$^{-1}$ live weight).

The number of animals required for household consumption was:

$$O_{food} = \frac{LW_{gp} \times 1000}{W_{gp}}$$

Where:

- $O_{food}$ = guinea pigs required for local food consumption (animals·year$^{-1}$).
- $LW_{gp}$ = required guinea pig live weight production (t live weight· year$^{-1}$).
- $W_{gp}$ = average live weight per animal (kg· animal$^{-1}$).
- 1000 = conversion factor from tonnes to kilograms.

S2.6.3) Animal stock estimation

The standing animal fund was estimated from the average herd size maintained by each producer household:

$$Stock_{gp} = S_h \times H$$

Where:

- $Stock_{gp}$ = standing guinea pig population maintained by the community (animals).
- $S_h$ = average guinea pig stock per producer household (animals·household$^{-1}$).
- H = number of households involved in guinea pig production (households).

The relationship between annual production flow and standing animal fund was evaluated using the output-to-stock ratio:

$$OSR = \frac{O_{total}}{Stock_{gp}}$$

Where:

- OSR = annual output-to-stock ratio, indicating the turnover intensity of the guinea pig animal fund (year$^{-1}$).
- $O_{total}$ = total annual guinea pig output (animal·year$^{-1}$).
- $Stock_{gp}$ = standing guinea pig population maintained by the community (animals).

This ratio links the livestock fund maintained by the community with the annual animal flow generated.

S2.6.4) Reproductive structure of the guinea pig population

The reproductive subsystem was reconstructed using herd demographic coefficients. The number of breeding females was:

$$BF = Stock_{gp} \times P_f$$

Where:

- BF = number of breeding females (females).
- $Stock_{gp}$ = standing guinea pig population maintained by the community (animals).
- $P_f$ = proportion of reproductive females.

Breeding males:

$$BM = BF \times R_m$$

Where:

- BM = number of breeding males (males).
- BF = number of breeding females (females).
- $R_m$ = male-to-female breeding ratio (males·female$^{-1}$).

Annual potential offspring production was calculated as:

$$B = BF \times L_f \times LS$$

Where:

- B = annual guinea pig births (offspring·year$^{-1}$).
- BF = number of breeding females (females).
- $L_f$ = litters per breeding female per year (litters·female$^{-1}$·year$^{-1}$).
- LS = average litter size (offspring·litter$^{-1}$).

Survival corrections were sequentially applied:

$$O_{max} = B \times S_b \times S_w \times S_g$$

Where:

- $O_{max}$ = maximum biologically achievable guinea pig output (animals·year$^{-1}$).
- $S_b$ = birth survival rate.
- $S_w$ = weaning survival rate.
- $S_g$ = growing phase survival rate.

The effective reproductive productivity per female was:

$$EP = \frac{O_{max}}{BF}$$

Where:

- EP = effective reproductive productivity (animals reaching productive age·female$^{-1}$·year$^{-1}$).
- $O_{max}$ = maximum biologically achievable guinea pig output (animals·year$^{-1}$).
- BF = number of breeding females (females).

S2.6.5) Human activity fund requirement

The human activity required for guinea pig management was estimated from animal husbandry requirements.

$$HA_{husbandry} = Stock_{gp} \times LC_{gp}$$

Where:

- $HA_{husbandry}$ = labor required for animal care (h· year$^{-1}$)
- $Stock_{gp}$ = standing guinea pig population maintained by the community (animals).
- $LC_{gp}$ = labor coefficient per animal (h· animal$^{-1}$·year$^{-1}$)

S2.6.6) Housing land requirement

The built infrastructure required for animal housing was included as a land fund.

$$LU_{housing} = Stock_{gp} \times A_{animal}$$

Where:

- $LU_{housing}$ = land occupied by guinea pig housing infrastructure (ha).
- $Stock_{gp}$ = standing guinea pig population maintained by the community (animals).
- $A_{animal}$ = housing area requirement per animal (ha·animal$^{-1}$).

The reference housing unit was defined according to the locally observed production infrastructure.

S2.6.7) Feed requirement calculation

The animal population was separated into productive categories:

- reproductive females,
- breeding males,
- growing animals.

Because growing animals represent an annual production flow rather than a permanent animal fund, the average standing stock of growing animals was estimated by converting the annual animal output into an equivalent animal fund using the residence time in the growing phase:

$$G_{Stock} = \frac{O_{max} \times D_g}{365}$$

Where:

- $G_{stock}$ = average standing stock of growing animals maintained in the system (animals).
- $O_{max}$ = maximum biologically achievable guinea pig output (animals·year$^{-1}$).

- $D_g$ = duration of the growing phase (days).
- 365 = conversion factor from years to days (days·year⁻¹).

Therefore, the animal number used for feed estimation was defined as:

$$N_i = \begin{cases} BF, reproductive\ females \\ BM, \quad breeding\ males \\ G_{stock,}\ growing\ animals \end{cases}$$

For each category:

$$Feed_i = N_i \times LW_i \times FI_i \times D_i$$

Where:

- $Feed_i$ = fresh matter feed requirement for item $i$ (kg· year$^{-1}$)
- $N_i$ = average standing animal fund in category $i$(animals)
- $LW_i$ = average live weight of animals in item $i$ (kg·animal$^{-1}$)..
- $FI_i$ = daily fresh feed intake coefficient for item $i$ (kg fresh feed·kg$^{-1}$ live weight·day$^{-1}$), expressed as a fraction of live weight.
- $D_i$ = number of feeding days for item $i$ (days·year$^{-1}$).

Total fresh feed requirement:

$$Feed_{total} = \sum Feed_i$$

S2.6.8) Feed partition: forage and concentrate

The guinea pig diet was separated into forage and concentrate fractions:

$$Forage = Feed_{total} \times C_f$$

$$Conc = Feed_{total} \times C_c$$

Where:

- Forage = annual forage requirement (kg fresh matter·year$^{-1}$).
- Conc = annual concentrate requirement (kg fresh matter·year$^{-1}$).
- $Feed_{total}$ = total annual guinea pig feed requirement (kg fresh matter·year$^{-1}$).
- $C_f$ = forage fraction in the diet.
- $C_c$ = concentrate fraction in the diet.

S2.6.9) Forage dry matter requirement

Fresh forage was converted into dry matter:

$$DM_f = Forage \times C_{dm}$$

Where:

- $DM_f$ = forage dry matter demand (kg dry matter·year$^{-1}$).
- Forage = annual forage requirement (kg fresh matter·year$^{-1}$).
- $C_{dm}$ = dry matter content of forage.

S2.6.10) Local forage land requirement

For locally produced ryegrass–clover forage:

$$LU_f = \frac{DM_f/1000}{Y_f}$$

Where:

- $LU_f$ = forage land requirement (ha).
- $DM_f$ = forage dry matter demand (kg dry matter·year$^{-1}$).
- $Y_f$ = forage dry matter yield (t dry matter·ha$^{-1}$·year$^{-1}$).
- 1000 = conversion factor from kg to tonnes.

S2.6.11) Concentrate feed subsystem

The concentrate component was treated as an external feed supply chain.

Dry matter concentrate demand:

$$DM_{conc} = Conc \times C_{DM,conc}$$

Where:

- $DM_{conc}$ = dry matter concentrate demand (kg dry matter·year$^{-1}$).
- Conc = annual fresh concentrate requirement (kg fresh matter·year$^{-1}$).
- $C_{DM,conc}$ = dry matter content of the concentrate mixture

Each ingredient requirement:

$$C_i = DM_{conc} \times R_i$$

Where:

- $C_i$ = dry matter demand of ingredient $i$(kg dry matter·year$^{-1}$).
- $DM_{conc}$ = dry matter concentrate demand (kg dry matter·year$^{-1}$).
- $R_i$ = ration fraction of ingredient $i$in the concentrate mixture.

Ingredients included:

- Barley.
- Alfalfa.
- Maize.

Fresh equivalent conversion:

$$FE_i = \frac{C_i}{C_{DM,i}}$$

Where:

- $FE_i$ = fresh equivalent demand of ingredient $i$ (kg fresh matter·year$^{-1}$).
- $C_i$ = dry matter demand of ingredient $i$ (kg dry matter·year$^{-1}$).
- $C_{DM,i}$ = dry matter content of ingredient $i$

S2.6.12) External agricultural land embodied in concentrate

For each imported feed component:

$$LU_i = \frac{FE_i/1000}{Y_i}$$

Where:

- $LU_i$ = external land embodied in imported feed component *i* (ha·year⁻¹).
- $FE_i$ = fresh equivalent demand of ingredient *i* (kg fresh matter·year⁻¹).
- $Y_i$ = yield of feed component *i* (t fresh matter·ha⁻¹·year⁻¹).
- 1000 = conversion factor from kg to tonnes.

Total external land

$$LU_{external} = \sum LU_i$$

S2.6.13) Feed production labor requirement

Labor embodied in feed production

$$HA_i = LU_i \times LC_i$$

Where:

- $HA_i$ = human activity embodied in production of feed component *i* (h·year⁻¹).
- $LU_i$ = external land embodied in imported feed component *i* (ha·year⁻¹).
- $LC_i$ = crop-specific labor coefficient (h·ha⁻¹).

Total

$$HA_{feed} = \sum HA_i$$

S2.6.14) Water requirement

Green water:

$$GW_i = PE_i \times gw_i$$

Where:

- $GW_i$ = green water requirement for feed component *i* ($m^3$·year⁻¹).
- $PE_i$ = fresh equivalent demand of feed component *i* (t fresh matter·year⁻¹).
- $gw_i$ = green water coefficient of feed component *i* ($m^3$·t⁻¹).

Blue water:

$$BW_i = PE_i \times bw_i$$

Where:

- $BW_i$ = blue water requirement for feed component $i$($m^3$·year⁻¹).
- $PE_i$ = fresh equivalent demand of feed component *i* (t fresh matter·year⁻¹).
- $bw_i$ = blue water coefficient of feed component $i$($m^3$·t⁻¹).

Total requirement:

$$GW_{feed} = \sum_i GW_i$$

$$BW_{feed} = \sum_i BW_i$$

## S3) SENSITIVITY ANALYSIS

### S3.1) Purpose and analytical framing

The MuSIASEM accounting estimated the annual labor requirement needed to sustain the locally produced provisioning flows considered in the study. However, direct information on household-level labor allocation, demographic structure, and agricultural labor calendars was not available. Therefore, the labor requirement could not be compared with a directly measured labor supply. To address this limitation, we conducted an aggregate labor-availability sensitivity analysis. The analysis compares the estimated annual labor demand with the potential annual labor supply of the community under alternative assumptions on working-age share, participation-equivalence, and annual labor-supply schedule. The analysis is framed as an upper-bound screening test: a negative labor balance identifies a labor constraint, whereas a positive balance is necessary but not sufficient to demonstrate realized labor availability.

Accordingly, the analysis does not estimate actual labor availability at the household level or during specific agricultural periods. Instead, it identifies the conditions under which the aggregate annual labor balance becomes constrained and reports the breakpoint at which the conclusion changes. Demand-side uncertainty and seasonal concentration are evaluated separately through tolerance and peak-load thresholds.

### S3.2) Input data and scenario assumptions

The sensitivity analysis uses the resident population (P), the annual labor demand estimated by the MuSIASEM accounting ($L_{DEM}$), and a set of exploratory assumptions describing the potential labor supply of the community. Because local demographic structure and household-level labor allocation were not directly measured, the analysis varies three supply-side parameters: the working-age share ($\omega$), the participation-equivalence factor ($\pi$), and the annual labor-supply schedule ($h_{SUP}$).

The assumptions used in the screening test are summarized in Table S1. Fixed inputs correspond to the population and annual labor requirement estimated in the main MuSIASEM accounting. Scenario parameters represent uncertainty in potential labor supply, demand-side tolerance, and seasonal concentration.

*Table S1. Input data and scenario assumptions for the labor-availability screening test*

| Component | Parameter | Value(s) used | Treatment in the analysis | Interpretation |
|---|---|---|---|---|
| Resident population | P | 171 persons | Fixed input | Total resident population included in the community-level MuSIASEM accounting. |
| Annual labor demand | $L_{DEM}$ | 82,852 h·year$^{-1}$ | Fixed baseline estimate | Annual labor requirement estimated by the MuSIASEM accounting for the locally produced provisioning flows. |
| Working-age share | ω | 0.55 / 0.65 / 0.75 | Supply-side sensitivity parameter | Represents uncertainty in the share of the resident population assumed to belong to the working-age group. |
| Participation-equivalence factor | π | 0.45 / 0.60 / 0.75 / 0.90 | Supply-side sensitivity parameter | Represents the fraction of the annual labor-supply schedule allocated by working-age persons to the modeled local activities. The value 0.45 is a depressed-participation stress level; 0.60–0.90 are upper-bound scenarios. |
| Annual labor-supply schedule | $h_{SUP}$ | 2,304 / 1,800 h·person$^{-1}$·year$^{-1}$ | Supply-side sensitivity parameter | Represents the annual number of hours supplied by a fully participating working-age person. It is treated as a substantive supply assumption, not as a neutral normalization unit. |
| Statutory supply schedule | $h_{SUP}$ = 2,304 | 48 h·week$^{-1}$ × 48 weeks | Reference scenario | Represents the Peruvian statutory full-time schedule used as the higher annual labor-supply schedule [9]. |
| Severe supply schedule | $h_{SUP}$ = 1,800 | In the AWU framework, 1,800 hours represents the minimum annual full-time figure when national provisions do not specify annual working hours, corresponding to 225 working days of eight hours each. | Stress scenario | This schedule was adopted as a severe lower labor-supply schedule, based on Eurostat's Annual Work Unit (AWU) convention. In this study, the 1,800 h schedule is not treated as a measured local agricultural labor standard, but as a stress scenario that reduces assumed annual labor supply relative to the Peruvian statutory schedule [10]. |
| Demand-side uncertainty | mD | Derived from $R_L$ | Demand-side tolerance indicator | Indicates how much the estimated annual labor demand could increase before the labor balance becomes negative. |
| Seasonal surge factor | σ | 1.0 / 1.3 | Seasonal sensitivity parameter | Represents a temporary increase in labor-time during peak periods. The value 1.3 is exploratory and should not be interpreted as measured capacity. |
| Peak labor concentration | κ | Not measured | Limitation / conditional parameter | Represents the empirical concentration of labor demand during peak periods. Because it was not measured, seasonal results are interpreted as thresholds, not as evidence that bottlenecks are absent. |
| Maximum tolerated peak concentration | $\kappa_{max}$ | Derived | Seasonal threshold | Indicates the maximum peak-to-average labor concentration that could be absorbed under each scenario. |

### S3.3) Core equations

The primary comparison was made in annual labor hours. Potential annual labor supply was estimated as:

$$L_{SUP} = P \times \omega \times \pi \times h_{SUP}$$

Where:

- P is the resident population.
- $\omega$ is the working-age share.
- $\pi$ is the participation-equivalence factor.
- $h_{\text{sup}}$ is the annual labor-supply schedule of a fully participating working-age person.

Moreover, the effective labor-availability share:

$$S_{LABOR} = \omega \times \pi$$

The annual labor balance was then calculated as:

$$B_L = L_{SUP} - L_{DEM}$$

and the labor supply-to-demand ratio as:

$$R_L = \frac{L_{SUP}}{L_{DEM}}$$

Where:

- $L_{SUP}$ = Potential annual labor supply (h·year$^{-1}$).
- $L_{DEM}$ = Annual labor demand (h·year$^{-1}$).
- $B_L$ = Annual labor balance (h·year$^{-1}$).
- $R_L$ = Labor supply-to-demand ratio (dimensionless).

Interpretation:

a) $B_L < 0$ means that the scenario is labor-constrained.
b) $B_L \geq 0$ means that no aggregate annual labor constraint is detected, but it does not prove realized labor availability.

For interpretability, results were also expressed in Full-Time-Equivalent (FTE) workers:

$$FTE_{DEM} = \frac{L_{DEM}}{h_{SUP}}$$

$$FTE_{SUP} = \frac{L_{SUP}}{h_{SUP}} = P \times \omega \times \pi$$

However, the main comparison remains the balance in hours ($B_L$) and the unit-free ratio ($R_L$).

### S3.4) Reported outputs and interpretation rules

The full factorial results are presented in Table S2. The table combines the evaluated values of the working-age share ($\omega$)and the participation-equivalence factor ($\pi$)under two annual labor-supply schedules. The abbreviation stat. refers to the statutory supply schedule ($h_{\mathrm{SUP}}$ = 2,304 h person$^{-1}$ year$^{-1}$), based on the Peruvian full-time reference. The abbreviation sev. refers to the severe lower supply schedule ($h_{\mathrm{SUP}}$ = 1,800 h person$^{-1}$ year$^{-1}$), used as a stress scenario. For each scenario, the table reports the effective labor-availability share ($S_{\mathrm{labor}}$), available full-time-equivalent labor ($FTE_{\mathrm{SUP}}$), required full-time-equivalent labor ($FTE_{\mathrm{DEM}}$), the FTE labor balance, the labor supply-to-demand ratio ($R_L$), and the corresponding screening verdict. Balances and ratios were computed using unrounded values; rounded values are shown only for presentation.

*Table S2. Full factorial labor-balance results under alternative supply-side assumptions*

| ω | π | SLABOR | FTESUP (SLABOR x 171) | FTEDEM,STAT (LDEM/2,304) | BFTE,STAT (FTESUP - FTEDEM(STAT)) | RSTAT (FTESUP / FTEDEM(STAT)) | Verdict (STAT) | FTEDEM,SEV (LDEM/1,800) | BFTE,SEV (FTESUP - FTEDEM(SEV)) | RSEV (FTESUP / FTEDEM(SEV)) | Verdict (SEV) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.55 | 0.45 | 0.248 | 42 | 36 | +6 | 1.18 | Not constrained | 46 | -4 | 0.92 | Constrained |
| 0.55 | 0.60 | 0.330 | 56 | 36 | +20 | 1.57 | Not constrained | 46 | +10 | 1.23 | Not constrained |
| 0.55 | 0.75 | 0.413 | 71 | 36 | +35 | 1.96 | Not constrained | 46 | +25 | 1.53 | Not constrained |
| 0.55 | 0.90 | 0.495 | 85 | 36 | +49 | 2.35 | Not constrained | 46 | +39 | 1.84 | Not constrained |
| 0.65 | 0.45 | 0.293 | 50 | 36 | +14 | 1.39 | Not constrained | 46 | +4 | 1.09 | Not constrained |
| 0.65 | 0.60 | 0.390 | 67 | 36 | +31 | 1.85 | Not constrained | 46 | +21 | 1.45 | Not constrained |
| 0.65 | 0.75 | 0.488 | 83 | 36 | +47 | 2.32 | Not constrained | 46 | +37 | 1.81 | Not constrained |
| 0.65 | 0.90 | 0.585 | 100 | 36 | +64 | 2.78 | Not constrained | 46 | +54 | 2.17 | Not constrained |
| 0.75 | 0.45 | 0.338 | 58 | 36 | +22 | 1.60 | Not constrained | 46 | +12 | 1.25 | Not constrained |
| 0.75 | 0.60 | 0.450 | 77 | 36 | +41 | 2.14 | Not constrained | 46 | +31 | 1.67 | Not constrained |
| 0.75 | 0.75 | 0.563 | 96 | 36 | +60 | 2.67 | Not constrained | 46 | +50 | 2.09 | Not constrained |
| 0.75 | 0.90 | 0.675 | 115 | 36 | +79 | 3.21 | Not constrained | 46 | +69 | 2.51 | Not constrained |

Note: FTE balances and ratios were computed using unrounded values; integer FTE values and balances are rounded only for presentation. A negative balance indicates a labor-constrained scenario, whereas a positive balance indicates only that no aggregate annual labor constraint is detected, but it does not prove realized labor availability at the household level or during peak agricultural periods.

The scenario corners were selected to summarize the main regions of the full factorial grid without repeating all combinations. They are not additional assumptions, but representative points used to interpret the screening results. The depressed corner (ω=0.55, π=0.45) represents the joint worst-case supply condition and identifies the breakpoint region. The adverse upper-bound corner (ω=0.55, π=0.60) represents the least favorable case within the upper-bound participation range. The mid corner (ω=0.65, π=0.75) provides a central reference case, while the favorable corner (ω=0.75, π=0.90) represents the most supply-favoring condition. Table S3 reports these four scenario corners and summarizes their critical supply schedule and demand-side margins.

*Table S3. Breakpoint and demand-side tolerance summary*

| Scenario corner | $FTE_{SUP}$ | ($h_{sup,crit}$) $h \cdot person^{-1} \cdot year^{-1}$ | Demand margin (STAT) | Demand margin (SEV) |
|---|---|---|---|---|
| | (P x ω x π) | ($L_{DEM}$ / $FTE_{SUP}$) | ($FTE_{SUP}$ x 2,304/$L_{DEM}$) -1 | ($FTE_{SUP}$ x 1,800/$L_{DEM}$) -1 |
| Depressed (ω=0.55, π=0.45) | 42.32 | 1,958 | +18% | −8% |
| Adverse upper-bound (ω=0.55, π=0.60) | 56.43 | 1,468 | +57% | +23% |
| Mid (ω=0.65, π=0.75) | 83.36 | 994 | +132% | +81% |
| Favorable (ω=0.75, π=0.90) | 115.43 | 718 | +221% | +151% |

$$S_{critical} = \frac{L_{DEM}}{P \times h_{SUP}}$$

- STATUTORY:

$$S_{critical,STAT} = \frac{82\,852}{171 \times 2304} = 0.210 = 21\%$$

- SEVERE:

$$S_{critical,SEV} = \frac{82\,852}{171 \times 1800} = 0.269 = 27\%$$

Seasonal concentration was evaluated separately because the annual labor balance does not guarantee that labor is available during peak agricultural periods. For each scenario corner, the maximum tolerated peak-to-average concentration was calculated as $\kappa_{\max} = \sigma \times R_L$. The base case assumes no seasonal surge ( $\sigma = 1$ ), while the exploratory case ( $\sigma = 1.3$ )represents a temporary 30% increase in labor-time during peak periods. Because the empirical peak concentration ($\kappa$)was not measured, Table S4 should be interpreted as a conditional threshold analysis, not as evidence that seasonal labor bottlenecks are absent.

*Table S4. Maximum tolerated peak concentration κ_max = σ × R (monthly resolution).*

| **Scenario corner** | $R_{STAT}$ | **$\kappa_{max} = \sigma_{base}$ x $R_{STAT}$ (σ=1) (STAT)** | **$\kappa_{max} = \sigma_{expl}$ x $R_{STAT}$ (σ=1.3) (STAT)** | **RSEV** | **$\kappa_{max} = \sigma_{base}$ x $R_{SEV}$ (σ=1) (SEV)** | **$\kappa_{max} = \sigma_{expl}$ x $R_{SEV}$ (σ=1.3) (SEV)** |
|---|---|---|---|---|---|---|
| | | **($R_{STAT}$ x σ)** | **($R_{STAT}$ x σ)** | | **($R_{SEV}$ x σ)** | **($R_{SEV}$ x σ)** |
| Depressed (ω=0.55, π=0.45) | 1.18 | 1.18 | 1.53 | 0.92 | 0.92 | 1.20 |
| Adverse upper-bound (ω=0.55, π=0.60) | 1.57 | 1.57 | 2.04 | 1.23 | 1.23 | 1.59 |
| Mid (ω=0.65, π=0.75) | 2.32 | 2.32 | 3.01 | 1.81 | 1.81 | 2.35 |
| Favorable (ω=0.75, π=0.90) | 3.21 | 3.21 | 4.17 | 2.51 | 2.51 | 3.26 |

Note: κmax indicates the maximum peak-to-average monthly labor concentration that could be absorbed under each scenario. Values are conditional on the assumed surge factor ($\sigma$). Since empirical $\kappa$was not measured, these thresholds should not be interpreted as observed seasonal feasibility.

Across the evaluated upper-bound participation range (π = 0.60–0.90), no aggregate annual labor constraint is detected under either annual labor-supply schedule. The only constrained case occurs under the joint depressed-participation stress scenario (ω = 0.55, π = 0.45) combined with the severe supply schedule ($h_{SUP}$ =1,800).

This identifies the breakpoint region rather than demonstrating general labor availability. Demand-side margins are wide in the mid and favorable scenarios, but narrow in the depressed corner. Seasonal thresholds are conditional because empirical peak concentration ($\kappa$) was not measured.

Therefore, the screening test should be interpreted as an aggregate annual capacity check, not as evidence of realized labor availability at the household level or during peak agricultural periods.

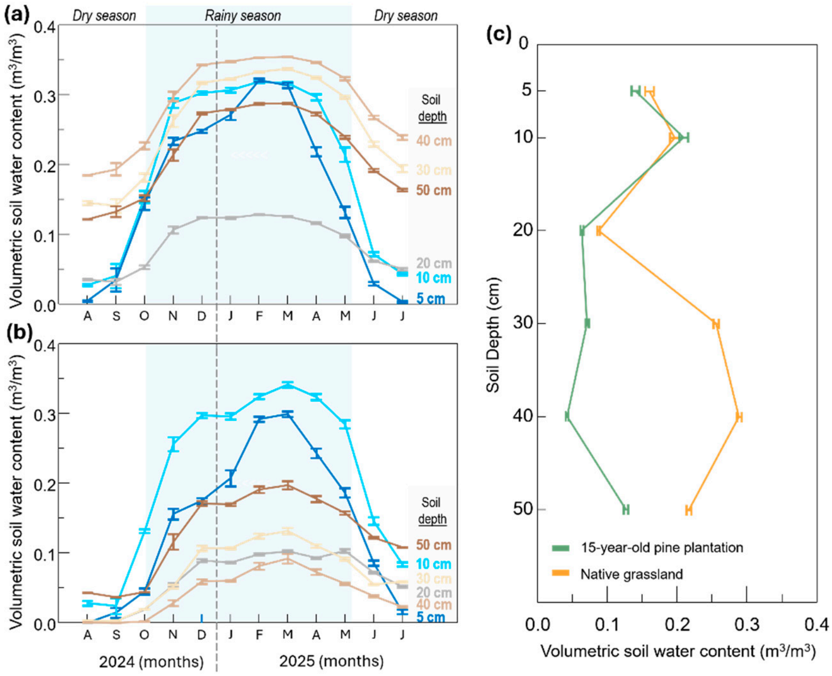


**Figure 1s.** Comparison of temporal dynamics and vertical distribution of volumetric soil water content (SWC) at six depths (5 – 50 cm) in native grassland (a) and 15-year-old pine plantation (b), and the mean vertical SWC profiles for both land covers (c) in Patapallpa Alta, Cusco – Peru.

## References


1. INEI Encuesta Nacional de Hogares ENAHO. Available online: https://proyectos.inei.gob.pe/microdatos/ (accessed on 2 April 2026).

2. Reyes García, M.; Gómez-Sánchez Prieto, I.; Espinoza Barrientos, C. Tablas Peruanas de Composición de Alimentos; Instituto Nacional de Salud: Lima, Peru, 2017.

3. Dehyfoods. Product Specification & Technical Data: Dehydrated Slippery Jack Mushroom/Suillus Luteus; Dehyfoods: Meiningen. Germany, 2023. Available online: https://dehyfoods.com/images/PDF/TechSpec_Suillus_luteus_all_2_3.pdf (accessed on 19 July 2026).

4. MacLean, W.C.; Warwick, P. Food Energy: Methods of Analysis and Conversion Factors: Report of a Technical Workshop, Rome, 3–6 December 2002; FAO Food and Nutrition Paper, 77; Food and Agriculture Organization of the United Nations: Rome, Italy, 2003; ISBN 9251050147.

5. FAO. Technical Conversion Factors for Agricultural Commodities; FAO: Rome, Italy, 2023.

6. MIDAGRI Perfil Productivo Regional. Available online: https://app.powerbi.com/view?r=eyJrIjoiN2U3NTdkYTktOTk5Ny00NjQ5LTg0ZjEtMmIzYzlmZWIwMDhlIiwidCI6IjdmMDg0NjI3LTdmNDAtNDg3OS04OTE3LTk0Yjg2ZmQzNWYzZiJ9 (accessed on 4 April 2026).

7. FAO FAOSTAT Datos Sobre Alimentación y Agricultura. Available online: https://www.fao.org/faostat/es/#home (accessed on 4 April 2026).

8. Mekonnen, M.M.; Hoekstra, A.Y. The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products. Volume 2: Ap-pendices; Value of Water Research Report Series No. 47; UNESCO-IHE Institute for Water Education: Delft, the Netherlands, 2010