**Supplementary material**

Brief step by step for the data collection protocols implemented in the context of Agrisys Tanzania.

**###ECOLOGICAL RESEARCH PROTOCOLS###**

**STEP 0: Plot setting**

1. Mark plot corners (20x20m), N-S orientation, start at SW corner, mark corners with tape and compass
2. Mark subplot (5x5m) and points S1-5
3. Mark 1x1m areas at s1-4

A screenshot of a cell phone

Description automatically generated

**STEP 1: Pollination**

1. Check for flowering plants within 20x20m plot.
2. Select four flowering plants of up to four species. If okra/pumpkin plot, prioritise those flowers. Annotate the plant species and number of corresponding flowering units.
3. Observe each plant for 15 minutes (4 assistants observing one plant each, plus 2 assistants doing data entry). Each assistant should use a timer.
4. Record all flower visitors that touch the sexual parts of flowers. Collect one specimen per morphospecies for later identification. Annotate number of visits by same morphospecies. Pause timer when processing collected insects.
5. Stop in case of heavy rain and restart 30m after rain stops.

**STEP 2: Pests and Predators**

1. Sample 4 1x1m areas at points S1-4. For each area 2 assistants spend 20 minutes manually inspecting for insects in contact with the plants inside the 1x1m, while an additional assistant does data entry. Each assistant should use a timer and stop it when processing collected specimens.
2. All morphospecies are collected, including insect predators, herbivores, and pests. If many individuals are present, abundance is estimated and only one specimen is collected per plant species. If crop plots, the specific crop the specimen was on is annotated. For other plants, only the general group is registered (e.g. “weed” if insect is found on a weed within a crop plot).
3. For aphids, caterpillars, leaf miners: specimens are collected for rearing. In case of aphid colonies, some individuals are also collected in alcohol for identification.
4. Reared specimens are kept up to one month. Check every 2 days, add food (fresh host plants collected from the field) and moisture (on a cotton roll) as necessary.
5. Before sending the material for identification, ideally also before adding alcohol to the vial, a photo should be taken of each morphospecies collected, when possible.

**STEP 3: Habitat Structure**

1. For trees: sample all trees (DBH≥5cm) inside 20x20m plot. Measure their DBH, height (for height measure alpha and beta angles with clinometer and distance to tree with measure tape). Also annotate presence of flowers/fruits.
2. For crops, shrubs, vines, herbs, seedlings, grasses: sample 4 1x1m areas at S1, S2, S3 and S4. Measure height and annotate presence of fruits/flowers. For wild herbs/seedlings/grasses, if multiple individuals are present in 1x1m area, register abundance of each species and only measure the highest.
3. For crops, shrubs, vines, herbs, seedlings, grasses: indicate visual signs of plant damage/disease.

**STEP 4: Canopy Structure**

1. Take three sequenced photos with hemispherical lens at points S1-12. Camera 1-m above ground. Top of camera is facing north.
2. The camera is set to auto-bracketing mode with three exposure levels: -1, 0, +1. Simply keep pressing the shooting button until you hear three shutter sounds.
3. Calibrate the Sunscan instrument before measuring each point.
4. Measure at S1-12. In each point, repeat the measurement from 3 different angles.
5. Take the Sunscan LAI reading by placing the probe in the vegetation closely above ground. Keep the sensor levelled. Make sure the sensor is not being shaded by people.

**STEP 5: Leaf Scans**

1. Measure leaf greenness (NDVI) using the MAPIR, leaf fluorescence using the SPAD 502 Plus Chlorophyll Meter, and leaf surface temperature using Optris PI450 Thermal Imaging Camera. For each scanned leaf, take these three scans at same spot (requires a minimum of 4 assistants).
2. Scan 10 leaves, including damaged leaves, in ten randomly selected plants per plot (2 plants in each plot section, i.e., middle 5x5m plus the 4 corners). Note amount of shading in each leaf. Try to measure same number of leaves under direct sunlight and leaves fully or partially shaded, when possible.

## Thermal

1. Use Optris PI450 Thermal Imaging Camera attached to a laptop.
2. The measurements will be collected on the lamina, avoiding the midrib.
3. Focus camera on the leaves from 40-50 cm distance.
4. Take the reading while holding a 2.5x2.5cm metal grid over the leaf.
5. Annotate the time shown in the laptop when scan was taken.
6. To calibrate instrument: Adjust emissivity with black tape with known emissivity = 0.98 in the field of view. Adjust the emissivity on the screen to 0.98 and take the temperature of the coloured surface. Determine the temperature of a directly adjacent area and modify the emissivity until the measured value corresponds to the temperature of the coloured surface.

## NDVI

1. Take photo of MAPIR calibration target. Register the time of image capture.
2. Focus MAPIR camera on the leaves from 40-50cm distance.
3. Take photo and include a 2.5x2.5cm metal grid holding it over the leaf. Metal grid should be aligned with the camera so that the grid has a square (not rhombus) shape without needing image editing.
4. Annotate the time shown in the MAPIR when scan/photo was taken.

## Fluorescence

1. Use SPAD 502 Plus Chlorophyll Meter
2. Always calibrate meter: clamp the measuring heads together with no sample in the meter. When calibration is complete, the meter will beep and display N=0.
3. Insert a leaf in between the meter heads. Close the measuring heads onto the leaf and hold until the meter beeps. The reading will appear on the display. Take readings ½ inch (~1cm) from edge of leaf, while avoiding the midrib.

**STEP 6: Ground Scans**

1. Sample at S1-5.
2. Use metal grid of 50x50cm and a coin to mark SW corner.
3. Use Optris PI450 Thermal Imaging Camera attached to the laptop. Camera positioned on pole and stabilised on tripod if possible.
4. Take a downward scan of the full grid at 1m height. S-N oriented.
5. Repeat with MAPIR camera.

**STEP 7: Earthworms**

1. Excavate soil from 20x20cm areas at S6 and S10 at depths of 0-20cm and 20-40cm.
2. Place the dug-up soil on a plastic bag. Break down the soil and keep any earthworms found on the bag.
3. Register earthworm abundance and morphospecies per sample depth.
4. Take picture of representative specimen for each morphospecies.
5. Put earthworms and soil back in the hole.

**STEP 8: Soil Visual Score**

1. Same sites as for soil earthworms (S6 and S10). Use same 20x20x40cm hole.
2. Use reference images to attribute visual scores for different soil features.
3. Take photo of the removed soil and the hole.
4. Attribute scores (half values are ok) to each of the following soil elements:
   1. Soil porosity: compare with reference images and attribute score
      1. 2= soils have many macro-pores between and within aggregates associated with good soil structure
      2. 1= soil macro-pores between and within aggregates have declined significantly but are present upon close examination of clods, showing a moderate amount of compaction
      3. 0= no soil macro-pores are visually apparent within compact, massive structureless clods. The clod surface is smooth with few cracks or holes and can have sharp angles.
   2. Soil colour: compare with reference images and attribute score
      1. 2= dark coloured topsoil that is not too dissimilar to that from the uncultivated area.
      2. 1= colour of the topsoil is somewhat paler than the uncultivated area, but not markedly so
      3. 0= soil colour has become significantly paler compared with the uncultivated area.
   3. Soil mottles: compare with reference images and attribute score
      1. 2= mottles are generally absent
      2. 1= soil has common (10-25%) fine and medium orange and grey mottles.
      3. 0= soil has abundant to profuse (>50%) medium and coarse orange and particularly grey mottles
   4. Earthworm count
      1. 2= >8
      2. 1= 4 - 8
      3. 0= <4
   5. Degree of clod development: compare with reference images and attribute score
      1. 2= good distribution of the friable, finer aggregates with no significant clods. A good seedbed is easily prepared
      2. 1= soil contains significant proportions of both coarse firm clods and friable fine aggregates. If cultivation is not carefully timed, clods slow significant tillage resistance
      3. 0= soil dominated by coarse, very firm clods with fewer finer aggregates. Clod resistance is high and the window for successful cultivation is very narrow
   6. Degree of erosion
      1. 2= wind erosion is not a concern: only small dust plumes emanate from the cultivator on windy days. Most wind-eroded material is contained within the field. Water erosion is not a concern as there is only a little rill and sheet erosion. Topsoil depths in valley areas are <15cm deeper than on crests. Deal with water erosion and wind erosion separately if both have occurred reduce the score by one point.
      2. 1= wind erosion is of moderate concern where significant dust plumes can emanate from the cultivator on windy days. A considerable amount of material is blown off the field, but is contained within the farm area. Water erosion is of a moderate concern with a significant amount of rilling and sheet erosion. Topsoil depths in valley areas are 15-30cm greater than on crests and sediment input into drains/streams may be significant.
      3. 0= Wind erosion is a major concern. Large dust clouds can occur when cultivating on windy days. A substantial amount of topsoil can be lost from the field and deposited elsewhere in the district. Water erosion is a major concern, with severe rilling and sheet erosion occurring. Top soils in valley areas are more than 30cm deeper than on the crests and sediment put into drains/streams may be high.
   7. Soil structure and consistency: compare with reference images and attribute score
      1. 2= good distribution of finer aggregates with no significant clodding
      2. 1= soil contains significant proportions of both coarse firm clods and friable, fine aggregates
      3. 0= soil dominated by extremely coarse, very firm clods with very few finer aggregates
   8. Sum previous rankings
      1. Poor: <10
      2. Moderate: 10-25
      3. Good: >25

**STEP 9: Soil pH (wet)**

1. Use Lutron PH-212 Soil pH Meter to take the measurements.
2. Same sites (S6 and S10) as for soil earthworms and visual score.
3. For each site, collect 5g of soil from the 0-20cm layer and mix it with 12.5ml water at 7.0 pH (i.e., use 1:2.5 soil/water ratio). Confirm water pH before mixing.
4. Place the electrode into the vial containing the solution.
5. After measurements, rinse the electrode in water.

**STEP 10: Soil collection for lab analysis**

1. Excavate soil from 20x20cm areas at S6 and S10 at depths of 0-20cm and 20-40cm.
2. Take composite S6+S10 samples at depths of 0-20cm and 20-40cm for future lab analysis.
3. Use soil core to take further 4 samples, one per point and per depth (at 10cm and 30cm), to determine bulk density.
4. Air dry the soil samples collected.

**STEP 11: Sugarcane Yield**

1. Sample five 1m2 areas at S1-5.
2. Count number of sugarcanes per area (count number of individual plants and canes). Canes coming from same base are counted as one individual.
3. Cut 2 representative canes from 2 plants per area at ground level and count number of canes in each. Annotate signs of damage/disease. (If only one individual in same sampling area, assistant should still cut and measure 4 canes, but this was not always done by the assistant, i.e., in some plots only 2 canes were measured when one individual had multiple canes).
4. Separate leaves from stalks and measure stalk height, weight, and diameter. Also measure total leaf weight.

**STEP 12: Okra Yield**

1. Sample five 1m2 areas at S1-5.
2. Count number of okra plants in each area.
3. Select 10 okra plants, ideally two per area.
4. Measure height of each sampled plant and count number of both mature and immature okras, as well as the number of cuttings where okras were previously harvested.
5. Collect all mature okras.
6. Weight mature okras collected.

**STEP 13: Maize Yield**

1. Sample five 1x1m areas at S1-5.
2. Count the number of maize plants per area. Stalks coming from same base are counted as one individual.
3. Randomly select 10 maize plants, ideally 2 per area. For each plant selected, measure its height, annotate number of ears and signs of plant damage/disease.
4. Collect all mature ears in the plants sampled. Measure ear weight and then shell the ears and weigh the grain.

**STEP A: Mammal Survey**

1. Define camera trap locations throughout the study area.
2. Ensure that batteries are charged, that SD cards are empty, that time and date are set, that all the correct settings have been applied.
3. Install camera in the location that will give the highest probability of obtaining useful photographs within 30m of the initially proposed point. The attachment point of the camera should be 2-3m from the point of interest to increase detection zone and ideally the camera should be facing perpendicular or 45° to an animal trail.
4. Use the GPS to record camera location. In addition, record date, time, camera trap ID and SD card ID, as well as a short description of the location.
5. Revisit every 3-4 weeks to download data, check/replace battery and replace memory card. Record any changes to the camera.

**###SOCIAL RESEARCH PROTOCOLS###**

**Focal Groups**

1. Develop a list of key questions aiming to understand local perceptions and knowledge about research topics of interest.
2. Obtain research clearance from the responsible ethics committee.
3. Identify participants with the assistance of local leaders. Aim to aggregate participants in groups that share similar characteristics (e.g., gender).
4. Organise all logistics, including finding a suitable venue and obtaining required materials and equipment.
5. Prepare a meeting plan and hire/train a facilitator.
6. Make sure free, prior, and informed consent is obtained before starting.
7. Take notes during the meeting and audio record it.

**Household Surveys**

1. Select the sampling area.
2. Design a semi-structured questionnaire focused on the research topics of interest.
3. Our questionnaire was translated to Swahili and reverse translated to English to guarantee that the questions maintained their original meaning.
4. Obtain research clearance from the responsible ethics committee.
5. Conduct a pilot study and make any required adjustments to the questionnaire.
6. Carry out a stratified random sampling approach for household selection. Sample should account for gender and, if possible, socio-economic category, to guarantee that all social groups are adequately represented.
7. Make sure free, prior, and informed consent is obtained before starting the questionnaire.

**Participatory Workshops**

1. Gather and review existing data on the research topic and determine the aims of the workshops. They were conducted in our study landscape to understand the viewpoints of often under-represented stakeholders. We identified participants through a stakeholder mapping exercise and discussion with stakeholders in the landscape.
2. Obtain research clearance from the responsible ethics committee.
3. Design a participatory workshop method focussed on the research topics and stakeholders of interest. Ideally, the workshops should also act as a knowledge exchange base, through which relevant information is shared and discussed with participants.
4. Conduct a pilot study and make any required adjustments to the methodology.
5. Carry out a stratified random sampling approach. Sample should account for gender, age and, if possible, socio-economic category, to guarantee that all social groups are adequately represented.
6. Make sure free, prior, and informed consent is obtained before starting.
7. Take notes during the meeting and audio record it.

**Key Informant Interviews**

1. Gather and review existing data on the research topic of interest and determine if key informant interviews are necessary. They were conducted in our study landscape to get further information on topics discussed within participatory workshops.
2. Obtain research clearance from the responsible ethics committee.
3. Determine preliminary questions or topics for interviews based on the topic of interest.
4. Identify key informants.
5. Design an interview based on the research topics of interest. This may be different depending on the key informant and their knowledge base.
6. Determine interview type. Our interviews were done face-to-face by experienced local facilitators in Kiswahili.
7. Make sure free, prior, and informed consent is obtained before starting the interview.
8. Take notes during the meeting and audio record it.