WHAT IS IT?

This code is included as Supplementary Materials for the article "An Agent-Based Model of Inter-Species Interactions in Agroforestry Systems". We constructed a model defined over a field represented as an area of 210x210 pixels with 20x20 ilex paraguariensis plants and 20x20 consociations or near-neighbour interactions, one set of 4 interactions for each ilex plant with its 4 equidistant tree neighbours. For each of 9 species of trees there are 2x20 consociations with ilex paraguariensis, one set of 4 interactions for each tree with its 4 equidistant ilex plants. There is one control of 2x20 ilex paraguariensis in the absence of trees. The mate plants make a grid with positions {10, 20, 30…., 200} in both the x and y coordinates. The trees make a grid with positions {5, 15, 25…., 195, 205} on the x-axis, with each x-coordinate designating one tree species that makes a whole row with positions {5, 15, 25…., 195, 205} along the y-axis (a column). There are two columns for each tree species, with adjacent x coordinates. The last two columns at x 195 and 205 are empty of trees but contain ilex paraguariensis, designated as a row of mate not consociated with trees. This is the control.

The distance between plants is 10 pixels, representing 1.5 meters in the actual experiment on the field. Thus, 1 meter is 6.67 pixels, and the NetLogo world represents an are of just over 1,000 squared meters.

Summarizing, there are initially 20x20 = 400 plants of ilex paraguariensis of which 400-40 == 360 are consociated with trees, and 40 are not consociated with any tree. There are 42 trees of each species, making a total of 9x42 = 378 trees. The species are listed in the code, an acronym is used for compact id, and the species are numbered.

For ease of keeping track, these are the xy offsets for the creation of the 9 species of trees: to create-species
[breed-name start-x start-y colour]
let coordinates [[5 5] [5 15] [5 25] [5 35] [5 45] [5 55] [5 65] [5 75] [5 85] [5 95] [5 105] [5 115] [5 125] [5 135] [5 145] [5 155] [5 165] [5 175] [5 185] [5 195] [5 205]]

The x coordinate is creating adding 10 to the previous one iteratively, while the positions on the y axis are fixed.

The approach aims to use structured breed names, combined with flexible, parametrized agent creation, thus setting a strong foundation for a complex ecological or environmental simulation. This method enhances the modularity, readability, and scalability of the model, supporting detailed ecological dynamics and interactions.

HOW IT WORKS

The model simulates soil fertility dynamics and plant growth in an agroforestry system. Here's an overview of the key processes:

Soil Fertility and Energy:
- Soil fertility is categorized into five levels, each mapped to a 'soil factor' that modulates plant growth and energy dynamics.
- Plants extract energy from the soil to grow.
- Plants are harvested, and trees are prunned and thinned. The organic matters goes back to the soil.
- The model uses 'soil-energy' as a working variable to track changes before updating the main 'soil' variable.

- Energy flows between soil and plants, with plants depleting soil energy as they grow and returning energy through various processes.

Each species starts with a default energy, and each soil quality endows the plants with a given energy. The growth rate of all plants depends on the soil quality and the species. Their growth rate is modelled from measured allometric data from the experiment in 2014 and 2015, referenced in the manuscript. The available photosynthetic available radiation (PAR) was measured in 2018, and it is useful here as a control to verify that the competition assigned to consociations scales with field experiments.

Cañafístola 1,33
Anchico 1,32
Lapacho 1,49
Loro negro 1,44
Araucaria 1,25
Guatambú 1,56
Toona 1,64
Grevillea 1,35
Kiri 1,54

There are direct and indirect interactions between agents. As trees grow, their shade competes the growth of ilex plants directly, occluding and causing a decrease in their rate of growth. Trees are trimmed, and the branches decompose in the soil increasing the fertility. The same happens with the remnants of the harvest. When tree density is thinned, the logs remain in the ground as well. These are the endogenous sources of organic matter, which have small differences across species. The availability of added, exogenous, fertilizers is enhanced by the amount of organic matter in the soil. These second order effects are one type of indirect interaction between agents. Each tree species also causes changes in soil micronutrients. For instance, we have measured different soil contents of Phosphorous for each species. These are another source if indirect interaction between agents.

ENERGY: SOIL GROWTH HARVEST TREES FERTILIZATION

The user chooses a soil Fertility level within 5 categories. These are arbitrary numbers, but what matters is the ratios between changes in soil resources caused by different processes.

During Set-Up, the chosen starting Fertility is transferred to a Soil variable called simply “soil_i”, i=1,2,3,4,5 for the 5 categories: set soil_i fertility

One of the objectives of implementing an agroforestry system is to restore the soil mainly through the recovery of soil organic matter (SOM). Trees are trimmed and thinned (or prune) and left to decompose in-situ. In addition different species of trees cause different changes in elemental composition and micronutrients, most likely through specific associations with funghi and microorganisms. Organic matter is also contributed by the harvest of ilex, as a percentage of the trimmed plants is left on the ground.

We declare as Global variables : Globals [….soil-multiplier-mate soil-multiplier-trees soil-multiplier soil-gain]

These soil multipliers contribute directly to the “soil energy” or richness of the soil as a “soil-gain” which is computed as a proportion of the total carbon-rich mass produced. This organic matter also buffers the pH of the soil and directly increaes the proportion of externally added fertilizers available to plants.

We declare as field variables, patches-own […soil soil_i (i,1,..5) soil-energy…..]

The soil value chosen during Set-Up, the chosen starting Fertility, is later transferred to Soil and this value is updated to account for the different contributions.

Each soil fertility level or category is mapped onto a soil factor which will be used to modulate the growth rate of ilex and trees, their capacity to take "energy" from the soil, and the volume produced as harvest, trimming, and thinning, closing the loop. If the system is working soil fertility will slowly increase with time.

The following is the sequence of events that updates the soil.

Set-Up Stage:
1. User selects an initial Fertility level.
2. The chosen value is stored as 'soil' and categorized into one of five 'soil_i' types.
3. Growth rates for agents are defined, agents are created, and variables (e.g., energy levels, soil multipliers) are initialized.

●User chooses a starting Fertility level
●Set-up stores the chosen value as "soil" and as a soil type: "soil_i", i=1,…5
(the starting fertility is mapped to variables soil and soil_i, i=1,…5)
●All plants are created and distributed on the field.
●The growth rate values for the agents are defined.
●The variables for iterative simulations are initialized, such as energy leves and soil multipliers from harvest, prunning, and thinning.
●The timing is established for growth, harvesting, fertilizing, trimming, and thinning.

Simulation: To-Go
●set-soil-factor
Each category of soil is mapped to a multiplier, the variable "soil-factor".

●energy-account
- Uses "soil-energy" as a working variable to track soil changes (facilitates debugging).
- Maps "soil" value to "soil-energy".
- Assigns energy values to plants based on soil type and soil-factor using "et" (energy trees).
- Plants grow by depleting soil energy.
- Harvesting, trimming, and thinning partially deplete plant energy.
- These processes return carbon-rich matter to the soil, gradually improving soil quality.

With these values ilex plants and trees start to grow using part of the energy of the soil, that is depleting the soil, while their energy is partially depleted by the interventions of harvesting, trimming, and thinning. This recursion in the sizes of the plants result in carbon-rich matter being added back to the soil, which needs to be accounted for until they update the value of "soil-energy" and "soil". This process is not instantaneous. As the soil changes, the energy assigned to plants is reset and that takes care of the cycle in a simplified version.

Energy Cycle:
- Plants deplete soil energy through growth.
- Interventions of harvesting, trimming, and thinning, take some energy away.
- Management practices (harvesting, trimming, thinning) return organic matter to soil.
- Changes in soil quality lead to recalibration of plant energy assignments.

- This cycle is simplified in the model, acknowledging that in reality, the process is not instantaneous.

The model aims to capture the complex interactions between plants and soil in an agroforestry system, demonstrating how management practices can lead to sustainable improvement in soil fertility over time.

●To Grow

The grow procedure simulates the growth of all plant species in the model. Growth rates are the experimental allometric parameters, and are multiplied by the soil-factor that determines the condition:

1. For each species (species0 to species9):

- Calls grow-at-rate with the species-specific growth rate
- grow-at-rate increases the size of each plant based on its growth rate and the soil factor:
  size = size * (1 + growth_rate) * soil_factor

1. Calculates total energy uptake for growth:
   growth-energy-uptake = (et * Ni + et * Nt) / 3
   Where:

- et: energy available to trees
- Ni: number of ilex plants
- Nt: total number of trees

1. Reduces soil energy based on growth energy uptake:
   Each patch's soil-energy is decreased by growth-energy-uptake

ask turtles grow-at-rate-variable
record the energy uptake as growth-energy-uptake

The soil is asked to loose the energy taken by the trees and ilex:
ask patches set soil-energy (soil-energy - growth-energy-uptake)

●harvest
The harvest procedure simulates the periodic harvesting of Ilex (yerba mate) plants in the agroforestry system.
Harvesting occurs at predefined intervals, set during the setup:
[24 76 128 180 232 284 336 388 440 492 544]
These represent ticks (time steps) when harvesting takes place, with the first harvest at tick 24 (June of the first year) and subsequent harvests every 52 ticks (annually).

The To-Harvest-Ilex and To-Harvest-Mate reduce the size of ilex plants by the percentage chosen in harvest-inensity. Standard practice in this experimental lot is 33%. Ilex plants loose a 1.21xPlant Reduction of their energy.

The size reduction in ilex plants is the harvest-amount. Total harvest stores this value summed over all ilex plants. Approximately 15% of this harvest amount remains in the soil and is mapped/stored in "soil-multiplier-mate", which is added to "soil-multiplier". The sum over all ilex of this 15% of the harvest amount becomes a “soil-gain-mate”, which is added to “soil-energy”. Soil-energy is updated.

Key Points
1. Only Ilex plants above a certain size (harvest-size) are harvested.
2. The harvest reduces both the size, by a chosen percentage (harvest-intensity, usually 33%), and energy of harvested ilex plants by 40%.
3. A portion of the harvest (15%) contributes to soil organic matter, improving soil quality.
- This is tracked in “soil-multiplier-mate”
- Added to the overall “soil-multiplier”
- Calculating “soil-gain-mate” as the sum of this 15% contribution from all ilex plants
- Updating soil-energy by adding soil-gain-mate
4. The procedure accounts for both the economic output (total-harvest) and the ecological impact (soil improvement) of harvesting.
5. Harvesting occurs at regular intervals, simulating annual harvests.

●fertilizing

The fertilizing procedure simulates the periodic addition of external nutrients to the soil. This process is crucial in agriculture to replenish soil nutrients and maintain soil fertility.

Timing:
Fertilization occurs at predefined intervals, set during the setup:
[40 92 144 196 248 300 352 404 456 508 560]
These numbers represent ticks (time steps) when fertilization takes place, with the first application at tick 40 (October of the first year) and subsequent applications every 52 ticks (annually).

When fertilization occurs, the following steps are executed:

1. Calculation of Fertilizer Amount:
   fertilizer-amount = (reposition / 100) * growth-energy-uptake * 1
   fertilizers-solubility soil-multiplier * buffer-factor

Where:
- reposition: User-defined percentage of energy to be replenished
- growth-energy-uptake: Energy consumed by plants during growth
- the SOM produce as soil-multiplier increases fertilizers availability to plants

1. Soil Gain Calculation:
   soil-gain = fertilizer-amount * (1 + 1 * fertilizers-solubility)

This calculation accounts for the enhancing effect of soil organic matter (represented by soil-multiplier) on fertilizer efficiency.

1. Soil Energy Update:
   For each patch:
   soil-energy = soil-energy + soil-gain

A switch “minreposition” can be used to choose fix or adjustable reposition. If minreposition? = True, the reposition is scaled back when soil improvements increases beyond 40%. If the soil improvement is better than 40%, then reposition is decrased: soil-energy-improvement > 1.4 [set reposition max list (reposition * 0.8) 10]

Key Points:
- The fertilizer amount is based on a percentage (reposition) of the energy consumed by plants during growth.
- The effectiveness of the fertilizer is doubled by the soil's organic matter content (soil-multiplier).
- This simulates how organic matter improves nutrient retention and availability.
- The procedure allows for dynamic adjustment of soil fertility based on plant growth and management practices.
- It represents a simplified version of the complex nutrient cycling processes in agroforestry systems.
- Fertilization occurs at regular intervals, simulating annual applications.

●trimming

The trimming procedure simulates the periodic pruning of trees branches in the agroforestry system, to reduce their crowns and incorporate material to the soil.

Trim factors are chosen conmensurate with the growth rates. Their product is one, meaning we trim more trees that grow more.

Trimming occurs at predefined intervals, set during the setup:
[36 88 140 192 244 296 348 400 452 504 556]
These represent ticks (time steps) when trimming takes place, with the first trim at tick 36 (September of the second year) and subsequent trims every 52 ticks (annually).

1. Trimming Calculation:

- Each species has a specific trim factor (ranging from 0.61 to 0.8)
- These factors are chosen to balance with growth rates
- For each tree:
    - harvest-trees = size * (1 - trim-factor)
    - New size = size * trim-factor
    - Energy is reduced by 0.3 * et * 1

1. Soil Organic Matter Contribution:

- 20% of the trimmed material (harvest-trees * 0.2) contributes to the species-specific soil multiplier
- These contributions are summed across all species

1. Soil Update:
   The update-soil-multipliers-trimm procedure is called to:

- Update soil-multiplier-trees with the total contribution from all species
- Update the overall soil-multiplier
- Calculate soil-gain for each patch (soil-multiplier-trees * Nt)
- Increase soil-energy of each patch

Trim-factors: [0.7 0.6 0.74 0.72 0.8 0.78 0.76 0.8 0.68]
These factors, when multiplied by their respective growth rates, equal 1, ensuring a balanced management approach across different tree species.

Key Points:
- Different tree species are trimmed at different rates, reflecting their growth characteristics
- Trimming reduces both the size and energy of trees
- A significant portion (20%) of trimmed material contributes to soil organic matter, improving soil quality
- The procedure accounts for both the management of tree growth and the ecological impact (soil improvement) of trimming
- Trimming occurs at regular intervals, simulating annual management practices

●thinning

The thinning procedure simulates the selective removal of trees in the agroforestry system to manage density and promote the growth of remaining trees. This process occurs in two phases and contributes significantly to soil organic matter. One every other tree with a size larger than 9 is cut down to size 1.

Setup:
- thiniter1?: Initially set to true, indicates the first thinning phase is ready
- thiniter2?: Initially set to false, indicates the second thinning phase is not yet ready
- thinned-count: Tracks the number of trees thinned in each operation

Approximately 15% of the mass of trees cut down becomes soil-multiplier-trees. The trees are counted, and the total soil-multiplier-trees summed over all reduced trees is mapped to soil-gain, which is added to soil-energy. Soil-multiplier-trees is the increment in the value of soil-multiplier which is updated.

Process:
The thinning occurs in two alternating phases, each targeting different rows of trees:
1. Thinning Operation (perform-thinning):
- Targets trees with size > 12
- Reduces the size of targeted trees to 1.0
- Counts the number of thinned trees
2. Thinning Phase 1 (thinning1):
- Targets trees at y-coordinates: 5, 25, 45, …, 205
- Adds 0.75 to soil-multiplier (representing ~9-10% of thinned biomass becoming soil organic matter)
- Records the current tick count (countert1)
- Switches to phase 2 for the next thinning operation
3. Thinning Phase 2 (thinning2):
- Targets trees at y-coordinates: 15, 35, 55, …, 215
- Adds 0.75 to soil-multiplier
- Switches back to phase 1 for the next thinning operation
4. Soil Update (update-soil-multipliers):
- Increases soil-multiplier-trees by the increment (0.75)
- Updates overall soil-multiplier
- Calculates soil-gain for each patch (soil-multiplier-trees * thinned-count)

- Increases soil-energy of each patch
Key Points:
- Thinning is triggered dynamically based on tree growth (size >= 9) rather than at fixed intervals
- The process alternates between two phases, ensuring even distribution of thinning across the plantation
- There's a minimum interval of 78 ticks between the first and second thinning phases
- Thinning targets mature trees in alternating rows across the simulation area
- The process significantly contributes to soil organic matter, improving soil quality
- Thinning helps manage tree density, promoting better growth conditions for remaining trees
Monitoring:
- current-soil-gain: Reports the most recent gain in soil organic matter from thinning
- current-soil-energy: Reports the current soil energy level, which increases after thinning operations

●Shade Competition
The shade competition procedure simulates the effect of tree shading on Ilex paraguariensis (yerba mate) plants in the agroforestry system, reflecting how larger trees can directly impact the growth of smaller plants beneath them.

The compete-shade procedure is called in each GO cycle and affects only species0 (Ilex paraguariensis):
1. Neighbor Identification:
- For each Ilex plant, identify all neighboring trees within a radius of 7.5 units.
- Select up to 4 closest neighbors. If fewer than 4 neighbors are within range, all available neighbors are considered.
2. Size Comparison:
- Calculate the average size of the selected neighboring trees.
3. Growth Adjustment:
- If the average size of neighboring trees is greater than 9:
* Reduce the size of the Ilex plant by a shade factor that can not be greater than 0.5: shade-factor max (list (1 - (avg-size / 30) ^ 2) 0.5), or
* Reduce the size of the Ilex plant by 10% (multiply size by 0.9)
- If the average size of neighboring trees is 9 or less:
* Allow normal growth for Ilex plants
Key Points:
- Only Ilex paraguariensis (species0) is directly affected by shade competition.
- The procedure models the shading effect of larger trees on understory crops.
- A maximum of 4 closest neighbors are considered to limit computational complexity while still capturing local effects.
- The size threshold of 9 for neighboring trees represents a critical point where shading becomes significant.
- The 10% size reduction for Ilex under large trees simulates reduced growth due to shade.
- Ilex plants under smaller trees (average size ≤ 9) can grow normally.

Ecological Implications:
- This procedure captures the trade-off in agroforestry systems between beneficial effects of trees (e.g., soil improvement) and their competitive effects (shading).
- It reflects the dynamic nature of plant interactions in multi-strata agroforestry systems.

- The model assumes that larger trees (size > 9) create significant shade that impacts understory crops.

Note: The specific values (radius of 7.5, size threshold of 9, 10% reduction) are parameters that can be adjusted based on field observations or to test different scenarios.

●Update Soil

The soil update procedure simulates the gradual incorporation of organic matter into the soil and the long-term changes in soil quality within the agroforestry system. This process represents the complex, time-dependent dynamics of soil organic matter decomposition and nutrient cycling.
Timing:
The rebalance-soil procedure is called every 26 ticks (approximately 6 months in the model's time scale):
if ticks > 1 and ticks mod 26 = 0 [rebalance-soil]

1. Organic Matter Decomposition:

- Every 52 ticks (annually), the soil-multiplier is halved:
  if ticks mod 52 = 0 [set soil-multiplier soil-multiplier * 0.5]

- This represents an approximate 1-year half-life for soil organic matter

The degradation of all carbon-rich sources and their incorporation to the soil is a slow gradual process that takes time. This "non-binary" source of complexity is simplified in the model with a periodic rebalancing of the soil every six months.

to rebalance-soil mappes the value of soil-energy to soil, and finds which of the 5 categories of soil this corresponds to. The color display is updated.
The reports "total-soil" and "total-soil-energy" display per-patch values and the "state-of-soil" icon displyes the evolution of soil-energy. The changes in energy-ilex and energy-trees are reported.

Process:
1. Organic Matter Decomposition:
- Every 52 ticks (annually), the soil-multiplier is halved:
if ticks mod 52 = 0 [set soil-multiplier soil-multiplier * 0.5]
- This represents an approximate 1-year half-life for soil organic matter
2. Soil Energy Update:
- The current-soil-energy value is mapped to the soil variable for each patch
- This represents the incorporation of accumulated organic matter and nutrients into the soil
3. Soil Classification:
The soil is reclassified into one of five categories based on its new energy value:
- soil1 (Highest quality): soil >= 8000
- soil2: 6000 <= soil < 8000
- soil3: 4000 <= soil < 6000
- soil4: 2000 <= soil < 4000
- soil5 (Lowest quality): soil < 2000
4. Visual Update:
- The color of each patch is updated to reflect its new soil category: soil1: pcolor 49 (dark green); soil2: pcolor 39 (medium green); soil3: pcolor 29 (light green); soil4: pcolor 19 (yellowish); soil5: pcolor 139 (brownish)
Key Points:

- The procedure simulates the gradual nature of organic matter decomposition and incorporation into the soil
- It reflects the concept that soil improvement is a slow, cumulative process
- The model simplifies complex soil dynamics by updating soil quality at regular intervals
- The visual representation allows for easy tracking of soil quality changes across the simulated area

Monitoring:
- total-soil: Reports the current soil quality values for each patch
- total-soil-energy: Reports the current soil energy values for each patch
- state-of-soil: A plot showing the evolution of soil energy over time
- Changes in energy-ilex and energy-trees are also reported, reflecting the impact of soil quality on plant growth

Ecological Implications:
- This procedure captures the long-term impacts of agroforestry practices on soil quality
- It demonstrates how various management practices (harvesting, trimming, thinning) contribute to soil improvement over time
- The visual representation helps in understanding the spatial distribution of soil quality improvements

Note: The specific values for soil categories and update intervals are parameters that can be adjusted based on field observations or to test different scenarios. The simplification of soil dynamics into discrete update events and categories allows for computational efficiency while still capturing the essential trends in soil quality change.

HOW TO USE IT

Items in the Interface tab

1. Fertility Slider:

- Range represents different soil qualities, classified into 5 soil types.
- Interesting to observe restoration of lower fertility levels as the system evolves.
- Each soil quality determines growth rates for plants.

1. Idlabel Switch:

- Adds species number to each plant for easy identification.

1. Network Switch:

- Creates linkages between ilex plants and their 4 closest trees.
- Link colors correspond to the linked trees’ colors.

1. Matrix Dropdown:

- Creates an adjacency matrix for the network of near neighbors to each ilex plant.
- Two options available for future development of more complex interactions.

1. State-of-soil Plot:

- Reports the “energy” or fertility state of the soil over time.
- Initial state set by “Fertility” slider.

- Shows how soil changes due to plant uptake, pruning, thinning, and natural processes.

1. Energy-trees Monitor:

- Reports available energy for plant growth.
- Reflects soil state through “soil-factor” value.

1. Energy Plot:

- Shows the complex flow and balance of nutrients in the system.
- Represents soil resources uptake by plants and feedback from organic matter.

1. Harvest-intensity Slider:

- Sets the percentage of ilex plants harvested.

1. Reposition Slider:

- Determines the amount of fertilizer added during fertilization events.

The state of the soil, or soil energy, or soil value within this classification in 5 soil types for the dynamic range chosen in Fertility, is also mapped to a “soil-factor” value to simplify operations. We use the soil-factor value to modulate the energy available to the plants and the growth of the plants.

ENERGY

The flow and balance of nutrients can be very complex, with multiple interconnected variables. Nutrients represent the available resources of the soil for uptake by the plants, it provides them the energy to grow. The reincorporation to the soil of tree branches and trunks feeds back to the soil and add nutrients both directly and indirectly.

THINGS TO NOTICE

1. Soil Quality Changes:

- Observe how soil color changes over time, reflecting fertility improvements or degradations.

1. Plant Growth Patterns:

- Notice differences in growth rates between ilex and different tree species.
- Observe how plant sizes change after harvesting, trimming, and thinning events.

1. Shade Competition:

- Look for areas where ilex plants grow slower due to shading from larger trees.

1. Soil Energy Fluctuations:

- Watch how soil energy changes after major events like harvesting, trimming, and fertilizing.

1. Network Dynamics:

- If network view is on, observe how connections between ilex and trees change as plants grow or are removed.

1. Species Distribution:

- Notice how the distribution of different tree species affects the overall system dynamics.

THINGS TO TRY

1. Fertility Experiments:

- Run simulations with different initial fertility levels and compare long-term outcomes.

1. Harvest Intensity:

- Adjust the harvest-intensity slider and observe its impact on ilex growth and soil quality.

1. Fertilization Strategies:

- Modify the reposition value to simulate different fertilization intensities.
- Compare aggressive vs. conservative fertilization strategies.

1. Species Balance:

- Try removing or adding certain tree species and observe the effect on system dynamics.

1. Management Timing:

- Experiment with different timings for harvesting, trimming, and thinning operations.

1. Climate Scenarios:

- If implemented, test the model under different simulated climate conditions.

1. Long-term Simulations:

- Run the model for extended periods to observe long-term trends in soil quality and plant growth.

1. Spatial Patterns:

- Analyze how initial planting arrangements affect long-term system development.

1. Optimization Challenge:

- Try to find the optimal balance of harvesting, fertilizing, and tree management for sustainable high yields.

EXTENDING THE MODEL

Shannon Entropy
to-report calculate-shannon-entropy let plant-sizes [size] of turtles let size-counts table:make foreach plant-sizes [size -> table:put size-counts size (table:get-or-default size-counts size 0 + 1)] let probabilities map [count -> count / length plant-sizes] table:values size-counts report -1 * sum (map [p -> p * log p 2] probabilities) end
Focusing on quantifying the complexity and information content of the agroforestry system as it evolves over time is an interesting approach. This can provide valuable insights into the system's dynamics and help validate the model's behaviour. Here are some ways one could approach this:
1. Shannon Entropy:
Calculate the Shannon entropy of the system at each time step.
This could be based on the distribution of plant sizes, soil qualities, or species abundances.
Increasing entropy over time might indicate growing complexity or diversity.

2. Species Diversity Indices:
Implement measures like Simpson’s Diversity Index or Shannon-Wiener Index.
These can quantify the biodiversity of your agroforestry system over time.
3. Spatial Complexity Measures:
Use metrics like Moran’s I or Geary’s C to quantify spatial autocorrelation.
This can help track how the spatial arrangement of plants changes over time.
4. Information Theoretic Measures:
Implement mutual information calculations between different components (e.g., soil quality and plant growth).
This can reveal how different parts of the system influence each other over time.
5. Network Analysis:
If your model includes interactions between plants, construct and analyze network metrics over time.
Measures like degree distribution, clustering coefficient, or centrality can quantify system complexity.
6. Fractal Dimension:
Calculate the fractal dimension of the spatial distribution of plants or soil qualities.
This can provide insights into the system’s spatial complexity.
7. Predictability Measures:
Implement methods to quantify the predictability of the system state over time.
This could involve time series analysis techniques or Lyapunov exponents.
8. State Space Analysis:
Track the system’s trajectory in a defined state space (e.g., total biomass vs. soil quality).
Analyze the properties of this trajectory (e.g., attractor characteristics).
To implement these in NetLogo, we would need to:
1. Define the relevant system states or variables to track.
2. Implement the calculation of these measures at each time step or at regular intervals.
3. Store and visualize the evolution of these complexity measures over time.

NETLOGO FEATURES

- Use of breed-specific variables to model different tree species characteristics
- Implementation of a complex soil quality system using patch variables
- Dynamic linking of agents to create a network representation of plant interactions
- Use of the ‘runresult’ primitive to dynamically execute breed-specific code
- Custom reporters for calculating various system metrics (e.g., energy levels, harvest amounts)
- Use of the ‘foreach’ command with complex lists to manage periodic events (harvesting, fertilizing, etc.)

RELATED MODELS

- “Rabbits Grass Weeds” - A simple ecosystem model demonstrating plant-animal interactions
- “Plant Growth” - Simulates basic plant growth patterns
- “Erosion” - Models soil erosion processes, which could be relevant to soil quality dynamics

- “Firefighters” - While not directly related, it demonstrates spatial management strategies that could be analogous to forest management
- “Scatter” - Useful for understanding how to distribute agents in space, which is relevant to tree planting strategies
- “Heatbugs” - Demonstrates how agents can affect and be affected by their local environment, similar to how trees interact with soil in your model

CREDITS AND REFERENCES

(a reference to the model’s URL on the web if it has one, as well as any other necessary credits, citations, and links)

DISCUSSION

Realistic Scaling: The model incorporates field measurements for growth rates and photosynthetic available radiation, ensuring that the relative sizes and competition levels between species are accurately represented. This is crucial for the model’s validity and predictive power.
2. Organic Matter Dynamics: The model accounts for the conversion of trimmed plant material into Soil Organic Matter (SOM), including the effects of harvesting and thinning. The rapid decay of this organic matter due to environmental factors like extreme weather is also considered, which attempts to add an important layer of realism.
3. Soil Quality Representation: While the five levels of soil quality are arbitrary, the relative scaling and evolution attempt to capture observed reality. This simplification allows for clearer visualization of system behaviour.
4. Local Effects: The model captures local variations in soil quality, competition, and plant growth, which is crucial for understanding the complex interactions between trees, ilex plants, and soil conditions. This localized approach is a strength of the model.
5. Comparative Analysis: The inclusion of a control lot without trees provides a valuable baseline for comparison with tree-integrated systems.
6. External Inputs: The model allows for the exploration of different levels of external fertilizer inputs, scaled as a percentage of harvested matter replacement. This feature enables the investigation of various management strategies.
7. Complex Interactions: The model successfully represents multiple layers of concatenated causes and effects, which would be difficult to predict without computational modelling.
8. Limitations: Many interactions (e.g., those involving microbial communities, fungi, insects, and birds) are not represented in the current model. This transparency about the model’s scope is important and should underpin future efforts at constructing more realistic ones.
The model attempts to provide a first tool for exploring the complex dynamics of agroforestry systems, particularly focusing on ilex production. The attention to realistic scaling and local effects is a starting point for additional measurements and the incorporation of more relevant interactions.