Lateral resource flow and capture - the key to scaling up agroforestry results

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Agroforestry research has followed the traditions of experimentation in agriculture and forestry. In relating results to the realities of farmers, however, we now realize that the rules for scaling up agroforestry results may differ from those for agriculture or forestry. Efforts to reduce 'lateral resource capture' by trees from neighbouring plots in experimental designs may solve one problem, but create new ones. Other research approaches may now be needed if we accept lateral resource flow in the landscape and lateral resource capture by trees as essential components of the real world of agroforestry on smallholder farms.

Maps are two-dimensional and this makes it easy to translate between scales, to zoom in and zoom out. The simplest approach to scaling up involves multiplying a surface area with an average value per unit area. Such scaled up estimates are all around us - but many of them may be wrong. The problem is that the 'average value per unit area' itself may depend on the scale. For example, the erosion of surface soil from one place can lead to sedimentation elsewhere. If we measure erosion on small plots and multiply the net sediment loss with the size of a watershed, we may get vast overestimates of the real sediment outflows, as we ignore much of the internal sedimentation. Similarly, if 'human migration' is defined as the crossing of some (administrative) border, counting migrants at a provincial scale and adding up the values for all districts will not give us the number of migrants at the national scale. At a global scale there is no human migration (apart from a few return trips to the moon).

Standard procedures for agronomic experiments involve attempts to make sure that the recorded yield values per unit area can be easily scaled up. Interference between plots is reduced by leaving guard rows out of the measurements. A major criticism of the majority of past agroforestry experiments has been that tree roots in agroforestry plots had access to neighbouring plots with other treatments (Coe, 1994). The ideal of agroforestry experimentation has thus become a situation where all resource capture is restricted to a vertical soil column under the plot and lateral light interception is minimised. But many of the techniques we investigate in trials will - in practice - be used as components of small farms and be part of a patchwork mosaic. Interference with neighbouring plots will be important in farm conditions. If we exclude this interference from the analysis of experimental plots we will have to explicitly bring it back into consideration later on. For example, research on 'improved fallows' carried out on small plots may show more tree biomass production from the fallow and higher crop yields per unit area than when larger plots are used. Much of the water and nutrient resources that account for this higher productivity, however, will have come from neighbouring plots. The conclusion that the productivity of the fallowed plot has increased can be correct, but that does not mean that farm level productivity will increase if this technology is introduced. Instead, the actual advantage of fallowing might simply be in reducing the area cultivated and thus in saving labour used.

In the parklands system of West Africa, we now recognize that a major role of trees such as *Vitellaria paradoxa* and *Faidherbia albida* is that of concentrating nutrient resources in 'fertility islands', rather than of creating new fertility. Expressing the positive effects of such trees on a per unit tree or area basis may easily lead to the conclusion that adding further trees to the landscape may increase the benefits - and this may be wrong.

Boundary planting has been recognized as an agroforestry technology - it is one of the major ways in which farmers introduce trees into their farms. Boundary plantings help to mark territories, but they are also an efficient way of capturing resources, especially if half of the resources come from the neighbour's plots (!) or from under-utilized land along footpaths, homesteads or roads. The productivitity of a boundary-planted tree can hardly be expressed on a unit area basis - it appears more logical to express it per unit length of boundary. Research on boundary plantings should probably focus on the question: where do the resources for tree growth really come from - by vertical or horizontal transfer? Extrapolations can then be made and whether adding trees will be beneficial overall evaluated.

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All these examples show that scaling up is not as straightforward as the use of two-dimensional maps suggests. We have to know to what extent the phenomena studied depend on 'lateral resource flow and capture' to understand how they behave at other scales.

Fractal dimensions

In the case of boundary plantings, lines [L^1], where L is length, rather than area [L^2] may be the appropriate basis for scaling. Many times it will have to be something in between [L^s]. Lines have dimension 1, surface area has dimension 2 and the 'something in between' is now indicated by a 'fractal' dimension (s). We can work with fractal dimensions in scaling, as if they were areas: if the fractal dimension is 1.6 and we want to extrapolate to a length scale which is 100 times larger, we multiply with $100^{1.6}$ = 1585 (instead of 100^2 = 10 000 where area is concerned; the difference is a factor of 6.3). Knowing the appropriate scaling rule may be at least as important as knowing the value per unit area on a small plot - especially where the extrapolation involves several orders of magnitude (Figure 1).

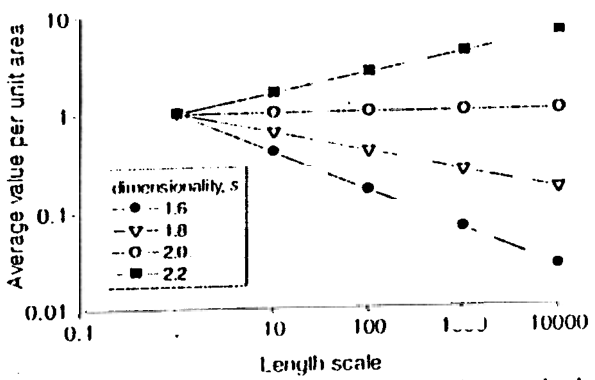

Figure 1. Different values for the dimensionality, s, lead to different results of extrapolation; a 20% error in the scaling rule has much more effect than a 20% error in the value for any given scale of measurement.

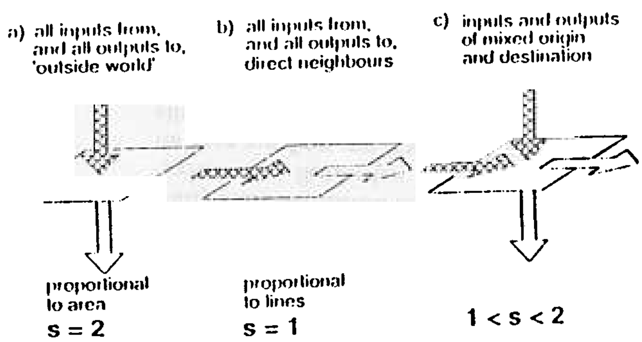

Figure 2. a) If all inputs come from, and outputs go to the outside world, an area-based approach with dimensionality of s = 2 may apply; b) if all inputs and outputs are laterally transmitted, a linear approach (s = 1) is appropriate; c) if inputs and outputs are of mixed origin and destination, a dimension between 1 and 2 may apply.

The vast majority of our current efforts are directed at knowing results per unit area - just look at any research report (e.g. ICRAF's annual report). Maybe it is time that the scaling rules received equal attention. Scaling rules themselves may change with scale - for most processes interactions become insignificant beyond a certain scale and we may revert to area-based approaches; for other processes, such as effects on market saturation or the likelihood of pest outbreaks, the scale effects continue (or may even increase).

The main reason for the dimensionality to differ from 2 is that there are local interactions at a range of scales. If all inputs come from outside the system, and all outputs leave the system, an area-based approach is correct (Figure 2a). If, however, some of the 'inputs' come from neighbouring areas, and/or some of the outputs go to neighbouring areas, the scaling rule differs from s = 2 (Figures 2b and c). This makes clear that the 'grain size' of the landscape pattern has an effect on the scaling rule. In fine-grained ('integrated') landscapes, with many boundaries between landscape units, the number of local interactions will be large and there are many reasons why s differs from 2. In coarse-grained ('segregated') patterns interactions between units will be small. Linking the scaling issue with interactions makes clear that we may have many of the tools needed to tackle the issue. At the plot or square metre scale, benefits or disadvantages of agroforestry are determined by 'interaction' effects. Interactions and the true resource base of systems at landscape scale come back here as critical issues to address.

A simple method exists for generating data with a fractal dimension. If we take a grid of random numbers, some of them negative, others positive and sample this grid at different scales (1x1, 2x2, 3x3, ...) with the rule that we record the net value, but take negative values as zero, we will find that the average value-per-unit-area decreases with the scale of sampling. At the 1x1 scale all negative values are perceived as zero, while at larger scales they can increasingly offset positive values. This analogy may help us understand the fractal dimension of net sediment loss in erosion studies as 'sedimentation sites' are recorded as sites of zero (and not negative) erosion. Yet sedimentation sites can offset nearby erosion if they occur within a single measurement unit.

Conventional agronomic experiments are done in 'fine grained' patterns, in the form of a patchwork of differently treated plots. It is a continuous source of concern that interactions such as lateral resource capture between the plots are not unduly influencing the results, so that these can be scaled up to the coarser grained patterns of real world farms. We have to pick up the challenge: we are dealing not only with 'experimental artefacts', but with important principles and results. We may be able to turn a problem into an opportunity if we can quantify how much 'lateral resource capture' contributes to the productivity of small scale plots.

Critical questions

1. How can we extrapolate from limited sets of observations/experiments to the landscape level and beyond?
2. Can 'lateral resource capture' be seen as an important element of agroforestry rather then as an 'experimental artefact', invalidating almost any experiment of the past (and present) from a scaling-up perspective?
3. What are the approximate scaling rules for the various functions of complex agroecosystems?
4. Can we indeed relate scaling rules to the degree of local interactions and thus to the grain size of the landscape pattern for the various functions in complex agro-ecosystems?
5. Can scaling rules contribute to our understanding of the 'political economy' of landscape processes and scale-dependent differences in perspective on desirable policy outcomes?

Approach

A 'nested' approach, including measurements of the same phenomenon at a range of scales (e.g. small plot, complete slope and sub-watershed in erosion and water-balance studies) can lead us to an empirical scaling rule *s*, but with additional process level studies we may also understand why this *s* value differs from 2.

Process level studies of interactions should complement inventory type approaches in stratified sampling. Examples of such processes are:

- run-off and run-on (surface flow of water),
- lateral flow of water and nutrients below the soil surface, either in the root zone or below,
- lateral resource capture by horizontally oriented tree roots,
- sedimentation studies accompanying erosion measurements: the fate of carbon and nutrients at sedimentation sites is largely unknown,
- species overlap determining the biodiversity scaling rule,
- corridor and fragmentation effects affecting survival of critical species,
- scale dependence of pest problems,
- relations between sources and sinks of methane at landscape level,
- microclimate effects of windbreaks vs dispersed trees.

The new agenda for research on 'scaling up to farm level and beyond' leads to a revisiting of some old dogmas and a new role for process studies

Landscape level transfers

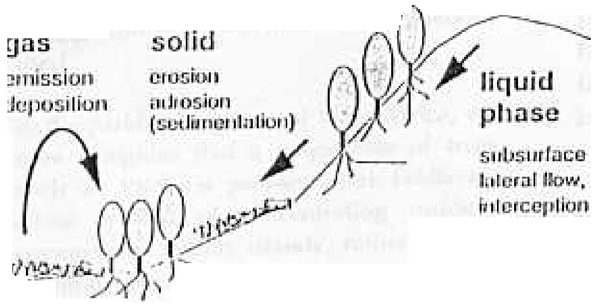

Figure 3. Landscape level resource flows and lateral resource capture determine the scaling rules.

The new agenda for research on 'scaling up to farm level and beyond' thus leads to a revisiting of some old dogmas and a new role for process studies. The toolbox for measuring lateral resource flow and lateral resource capture essentially exists - it can now be used for a new purpose.

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